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SURVEY OF AUSTRALIAN EXPERIENCE IN COLLECTING HIGH RESISTIVITY FLY ASH WITH ELECTROSTATIC PRECIPITATORS

Kenneth J. McLean

Wollongong University

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Prepared for

THE ENVIRONMENTAL PROTECTION AGENCY,
RESEARCH TRIANGLE, NORTH CAROLINA, 27701.

Contract No. 68-02-0245

Wollongong University College
University of New South Wales
WOLLONGONG, N.S.W. 2500.

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Sulfur Trioxide
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Physical Analysis

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ABSTRACT

A survey is made of the Australian experience in using electrostatic precipitators to collect fly ash resulting from the combustion of the low sulphur bituminous coal in pulverized fired boilers. This ash has a very high resistivity and is exceptionally difficult to collect, requiring in some cases, precipitators with specific collecting areas above 600 ft^2/kcfm. Typical precipitator dimensions and operating parameters are included together with a survey of the main problems and experience obtained in collecting this fly ash. The performance of the precipitators has been improved by operating at low temperatures and by conditioning the flue gas with sulphur trioxide and ammonia. The various conditioning injection systems are described and the effectiveness of the agents on the different ashes is discussed. Since the sulphur content of the coal cannot be used to reliably predict the electrostatic precipitating properties of the fly ash, pilot, technical scale and laboratory tests are carried out in order to determine the characteristics of the fly ash. These test procedures are described and evaluated. The report concludes with a comprehensive list of publications and reports related to the survey.

CHAPTER 1

METHOD OF COLLECTION AND PRESENTATION OF INFORMATION

1.1 Electricity Authorities Burning Low Sulphur Coals

The low sulphur bituminous coal deposits which are used for the generation of electrical energy are located along the east coast of the Australian continent in the states of New South Wales and Queensland. These reserves are being developed by three separate, government controlled, electricity authorities. The names of each of these authorities and their addresses are given below,

Electricity Commission of N.S.W. (ECNSW)	G.P.O. Box 5257, SYDNEY. N.S.W. 2001.
Southern Electric Authority of Queensland (SEAQ)	G.P.O. Box 403, BRISBANE. Qld. 4001.
Northern Electric Authority of Queensland (NEAQ)	P.O. Box 721, TOWNSVILLE. Qld. 4810.

The ECNSW has gained the most experience in collecting fly ash from low sulphur bituminous coals by electrostatic precipitators and consequently this report is centered around the information obtained from them. The SEAQ and NEAQ are both much smaller electrical authorities and have had much less experience. However the coal they burn is geographically from quite different areas so their test results and general experiences contribute significantly to the breadth of this report.

1.2 Method of Collecting and Evaluating Data

In order to collect and evaluate the data available in Australia, each of the electricity authorities was visited and the information obtained from the personnel directly involved with electrostatic precipitators and from official and unofficial records of tests. In the case of ECNSW, an office was made available and direct access given to all relevant data.

A large amount of material and data has been made available for assessment. The problem was, to select from sometimes conflicting evidence, that which was relevant to this report. The main guide line adopted was to make it sufficiently comprehensive so as to elucidate and yet not too detailed so as to be confusing. The correct balance between the two depends to some extent on the subjective judgment of the writer and it is hoped that a reasonable balance has been obtained.

Considerable assistance was obtained by office engineers in interpreting, evaluating and selecting information to be included. In order to confirm some of the conclusions, visits were made to the appropriate power stations and the views obtained from the station staff directly involved in some of the projects. The data and opinions expressed in this report are therefore drawn from many engineers directly involved with electrostatic precipitators. In the final analysis however, this information still has to be interpreted by the writer and presented in a manner that seems reasonable to him. While the report is therefore based on the very wide experience of engineers in Australia it must not be regarded as an expression of the official view of any one of them nor of the authorities who supplied information.

1.3 Some Aspects of Electrostatic Precipitator Theory

The method of presenting and interpreting the performance of electrostatic precipitators depends to some extent on the mathematical and physical models adopted to explain their operation. The approach used in this report is the traditional one which is extensively elaborated on by White (1) and more recently by Oglesby and Nichols (2). However, in order to appreciate the significance of some of the graphs in this report and the points raised in the discussion, some of the more important aspects of this model are explained in this section.

One approach, which at least has the advantage of starting with a theoretical expression, is to use the efficiency equation developed by Deutsch. As originally derived, this equation refers to the efficiency of collection of homogeneous particles all of uniform size. It is given by,

$$\eta = 1-\varepsilon^{-\frac{A}{Q}\omega} \qquad \text{.....(1)}$$

where, A = plate area
Q = gas flow rate
ω = migration velocity

In this case ω is the actual migration velocity for a given particle size. In an industrial situation, where the particles are seldom homogeneous, each particle size has its own theoretical migration velocity. If the penetration for each size is individually summed, the equation for the overall efficiency becomes,

$$\eta = 1 - \int_0^\infty f(a)\varepsilon^{-\frac{A}{Q}\omega(a)}\,da \qquad \ldots\ldots(2)$$

For any given particle size distribution, the penetration component of Eq. 2 may be calculated and then a value of ω determined so as to give the same efficiency when substituted in the equation,

$$\eta = 1-\varepsilon^{-\frac{A}{Q}\omega} \qquad \ldots\ldots(3)$$

This is the Deutsch-Anderson equation. It is essentially a semi-empirical equation in which ω has the dimensions of velocity and is called sometimes "effective drift velocity", "precipitation factor" and "effective migration velocity"(EMV).

One of the important limitations of Eq. 3 is that for a given set of electrical conditions in the electrostatic precipitator, ω will change as the A/Q varies (i.e. as the efficiency changes). This is a well known phenomenon and is reported on generally in the literature. Fig. 1.1 shows the variation of the migration velocity with particle size when field and diffusion charging is considered separately (29). Since the very fine particles are difficult to collect, their effect on the effective migration velocity (EMV) in the Deutsch-Anderson equation is to reduce its value as the efficiency improves. This is illustrated in Fig. 1.2. If the value of EMV at 95% efficiency is a given value, then to obtain 99.5% the value of EMV must be assumed to be half this value.

Another important factor which can cause considerable variation in the value of EMV is the temperature. The resistivity of in-situ fly ash increases for temperatures up to about 300^{o}F and then decreases at higher temperatures. Since the overall performance of a precipitator is an inverse function of resistivity, the effective migration velocity will vary with temperature, and have a minimum value at the temperature at which the resistivity is approximately a maximum.

The actual value of the effective migration velocity cannot be theoretically calculated even through Eq. 2. There are additional factors affecting the overall precipitator performance which are not taken into account in this theoretically derived equation. This includes such factors as gas turbulence, particle diffusion, electric wind, particle charging time and the voltage drop across the deposited layers (13). Additional factors found in practical precipitators include

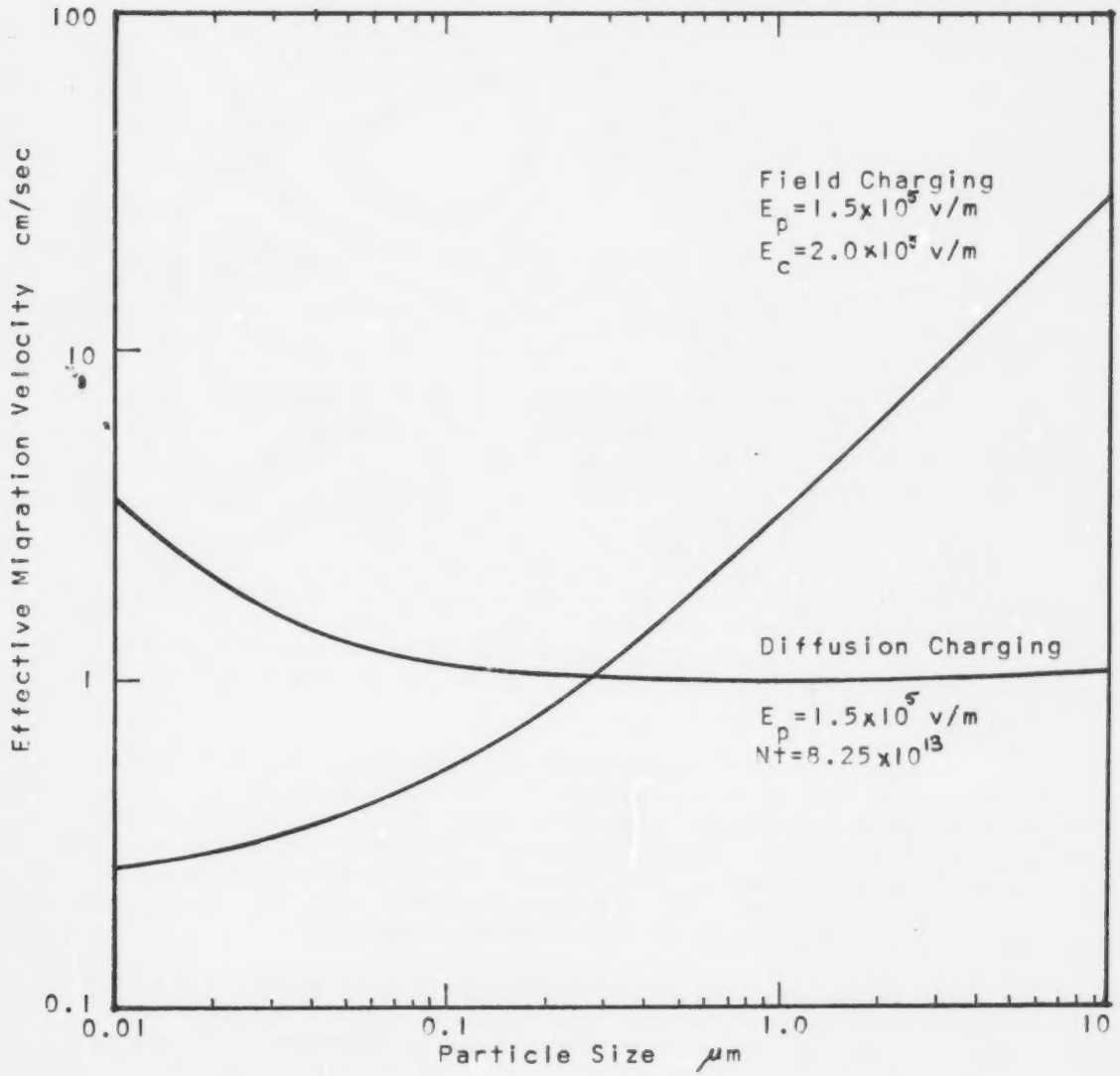

Figure 1.1 Relationship of Effective Migration Velocity and Particle Size for Field and Diffusion Charging.

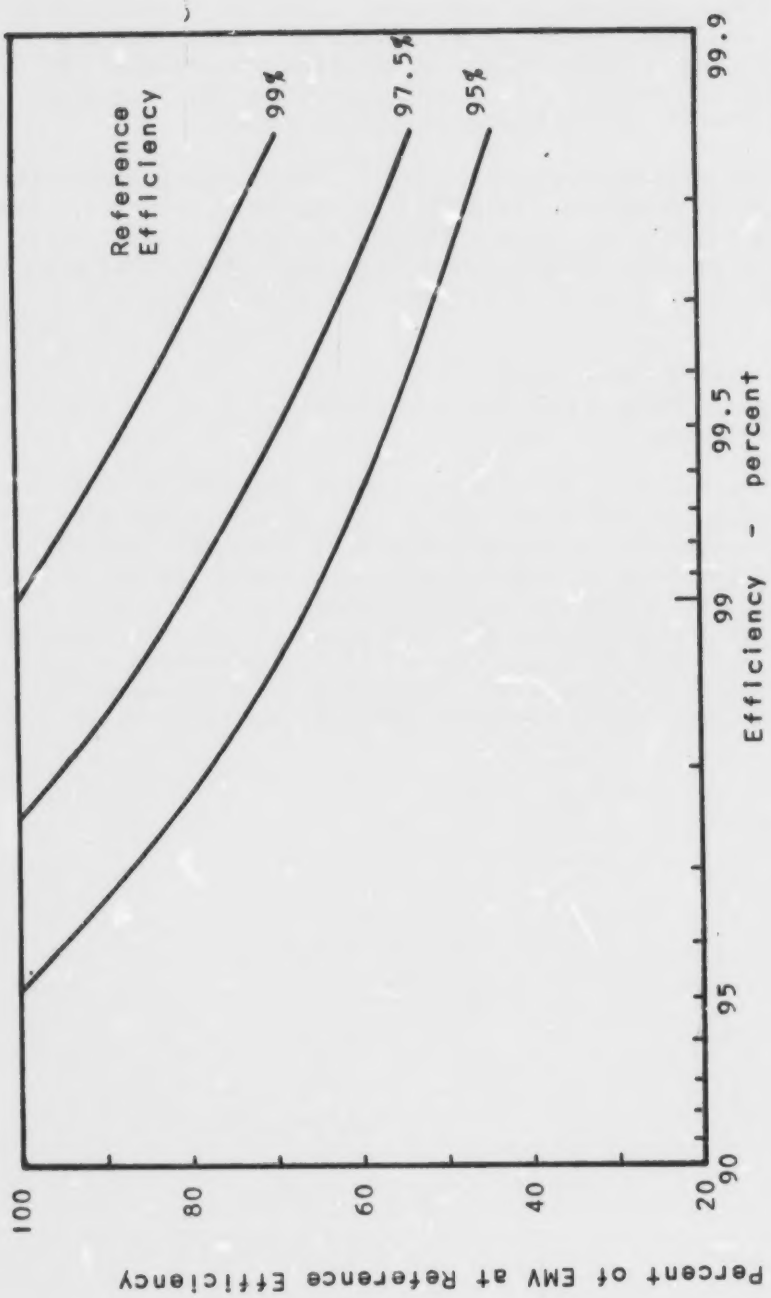

Figure 1.2 Reduction in effective migration velocity with increased precipitator efficiency.

such things as re-entrainment, gas velocity variation across the precipitator, reverse gas flows, temperature gradients, electrode misalignments and zone failures. All these result in an overall efficiency different from the theoretically calculated value. In practice the value of EMV is strictly an empirical constant. It is calculated from Eq. 3 in which the efficiency is measured, and the value of A/Q is known.

One method of quantifying the electrostatic precipitating properties of a given fly ash is to determine its effective migration velocity. Ash from low sulphur coals has a low value while ash from high sulphur coals has relatively higher values. Comparisons between different ashes are possible on this basis providing due consideration is given to,

(a) efficiency level, and
(b) temperature at which the efficiency is measured.

There could be some problem in correlating the value of the EMV calculated for one electrostatic precipitator to that calculated for another and it is theoretically possible that for a given ash, the EMV could vary for different makes of precipitators. It seems likely however, that provided the units are well maintained and adequately sized, the values will be similar for all full scale units. This may not be the case for the much smaller pilot scale units. Differences seem to occur with pilot scale units of different manufacturers and between the pilot scale and full scale units. This will be discussed more fully in Chapter 4.

CHAPTER 2

COAL AND FLY ASH CHARACTERISTICS

2.1 Introduction

The low sulphur bituminous coals of Australia are located along the east coast of the continent in the states of New South Wales and Queensland. They are mainly of Permian origin and possess inherent differences in mineral content when compared with the carbonaceous coal seams of Europe and North America.

In New South Wales, the coal used by the Electricity Commission of New South Wales in its pulverized fuel-fired power stations comes from four main sources; the Northern, Hunter Valley, Western and Southern coal fields. The first two of these are located roughly north of Sydney and the last two are respectively in the western and southern directions. Each coal field usually comprises a number of different seams, some of which have been extensively mined and others have had only small samples removed for testing. It is not uncommon for a number of different collieries to be located on the one seam. Coal may be designated by the seam name or by the colliery at which it is mined; both nomenclatures are extensively used. Tables 2.1 - 2.2 set out the main coal fields, seams and collieries from which coal has been burnt in existing power stations and the resultant fly ash tested for its electrostatic precipitating properties.

The main coal in the southern part of Queensland being fired in pulverized fuel power stations comes from the West Moreton field, located 25 miles west of Brisbane. Coal from the Blackwater field, 400 miles north west of Brisbane has been tested using a pilot scale plant and will be burnt in a future power station.

In the northern part of Queensland the main source of coal for the NEAQ is from the Bowen field located 120 miles south of Townsville.

2.2 Chemical (10)(11)(14)(22)(26)

Typical chemical properties of the New South Wales and Queensland low sulphur coals and resulting fly ash are given in Tables 2.1 - 2.3.

TABLE 2.1 - CHEMICAL COMPOSITION OF NSW COAL AND FLY ASH

(Dry Air Basis)

Coal Field		Northern		Hunter Valley
Seam	Gt. Northern	Wallarah	Fassifern	Bayswater
Colliery	Newvale			Ravensworth
Coal Analysis				
Cal. Value BTU/lb	11,950			9,130
Volatile Matter	30.6			23.4
Fixed Carbon	50.7			43.0
Moisture	3.1	2.0	2.0	4.0
Ash	15.6	12.3	16.5	30.0
Sulphur: Total	0.36	0.29	0.44	0.36
Pyritic	0.00			0.12
Sulphate	0.00			0.00
Organic	0.36			0.24
Ash Analysis				
SiO_2	55.6	50.3	56.1	57.8
Al_2O_3	29.6	28.2	26.5	28.9
Fe_2O_3	4.53	5.0	3.44	4.71
CaO	2.27	4.12	0.61	1.76
MgO	1.35	1.10	0.46	1.70
Na_2O	0.65	0.29	0.24	0.50
K_2O	2.98	0.30	1.04	1.27
SO_3	1.00	0.31	0.13	1.35
TiO_2	1.41	1.30	1.11	1.10
Combustible	-	8.3	9.6	-

TABLE 2.2 - CHEMICAL COMPOSITION OF N.S.W. COAL AND FLY ASH

(Dry Air Basis)

Coal Field		Western		Southern
Seam		Lithgow		Wongawilli
Colliery	Western Main	Wallerawang	Newcom	Huntley
Coal Analysis				
Cal. Value BTU/lb	10,740	11,480	11,040	9,720
Volatile Matter	26.9	28.5	29.1	22.8
Fixed Carbon	47.7	49.7	45.9	43.3
Moisture	10.0	9.0	7.0	1.1
Ash	15.5	12.6	17.9	32.8
Sulphur: Total	0.69	0.62	0.56	0.42
Pyritic				
Sulphate				
Organic				
Ash Analysis				
SiO_2	55.9	57.5	63.1	65.0
Al_2O_3	31.2	25.6	26.8	25.0
Fe_2O_3	2.45	1.22	0.59	7.24
CaO	0.56	0.82	0.51	0.33
MgO	0.32	0.24	0.30	0.48
Na_2O	0.06	0.06	0.12	0.07
K_2O	2.35	2.89	2.52	1.01
SO_3	0.22	0.22	0.30	0.20
TiO_2	0.92	1.10	0.88	0.60
Combustible	5.8	9.7	4.6	-

TABLE 2.3 - CHEMICAL COMPOSITION OF QUEENSLAND COAL AND FLY ASH

(Dry Air Basis)

Coal Field	Blackwater	West Moreton*		Bowen
Seam	Main Lower	Bluff Four Foot Bergin	Bowen	Blake
Coal Analysis				
Cal. Value BTU/lb	12,070	10,380	12,400	11,400
Volatile Matter	23.0	27.1	20.3	20.0
Fixed Carbon	61.5	44.9	61.0	56.2
Moisture	4.4	7.0	4.2	1.3
Ash	11.1	21.0	14.5	22.5
Sulphur: Total	0.43	0.27	1.3	1.14
Pyritic	0.21	0.06		0.58
Sulphate	0.02	0.00		0.16
Organic	0.20	0.21		0.40
Ash Analysis				
SiO_2	46.1	54.5	56.7	53.1
Al_2O_3	29.6	34.1	26.9	36.6
Fe_2O_3	3.71	3.4	10.5	1.4
CaO	2.86	2.4	1.1	0.8
MgO	1.5	1.5	0.3	0.4
Na_2O	1.9	0.1	0.2	0.2
K_2O	1.45	0.4	0.2	0.3
SO_3	0.49	1.0	0.3	0.3
TiO_2	0.86	2.2	2.4	2.2
Combustible	9.26	3.7	-	-

*Total ash analysis

The values recorded are typical for a test series which may have been conducted over a period lasting for several months. Variations however exist even in the same seam from one colliery to another so the values may only be taken as representative. The significant features of the composition of the fly ash when compared with the mean ranges encountered in the United States are;

(a) silicon oxide content is higher,
(b) iron oxide content is lower, and
(c) calcium oxide is generally lower.

It is also probable that the ratio of acidic components (SiO_2) to basic components (Al_2O_3, M_9O, CaO) is generally higher than in the fly ash from United States coals.

A very extensive analysis of the trace element content has been made on a large number of ashes and the results have been recorded elsewhere (10). Typical trace element content of fly ashes from two different coal fields is given in Table 2.4. The figures are given as parts per million on an air-dried basis.

No obvious correlation has been found between the coal or ash chemical composition or trace element content, and the electrostatic precipitating properties of the fly ash.

2.3 Physical Characteristics

(a) Sizing: During acceptance tests, the size distribution of the fly ash entering the inlet of the more modern electrostatic precipitators had a mean particle size from 19.0 to 27.5 μm when measured on the Bacho sizing instrument. (The mean particle size is the value below which 50 percent of the fly ash weight falls). For the older plants, at which most of the pilot scale tests were conducted, the mean particle size is in the range 7 to 14 μm.

(b) Density: The fly ash density while still warm varied over a fairly wide range as indicated, in Table 2.5.

Table 2.5 - Bulk Densities of Warm Fly Ash

Seam	Authority	Av. Density lb/ft^3
Lithgow	ECNSW	40.5
Bayswater	ECNSW	30.5
Main Lower	SEAQ	37.5
Blake	NEAQ	48.0

The density was found from the following measurements,

TABLE 2.4 - TRACE ELEMENT ANALYSIS OF FLY ASH SAMPLES FROM TWO NSW COALS

Seam / Colliery	Great Northern Newvale	Wongawilli Huntley
Element		
Ag	0.2	0.3
B	30	30
Ba	60	100
Be	1	2
Bi	10	20
Cd	50	100
Co	1.5	3
Cr	5	7
Cu	10	15
Ga	6	10
Ge	5	2.5
In	1.5	4
La	10	30
Mn	60	500
Mo	1	1.5
Ni	5	15
Pb	9	10
Sb	15	40
Sc	5	8
Sn	10	7
Sr	150	100
Th	50	100
Tl	10	20
V	15	15
W	10	20
Y	9	15
Zn	50	100
Zr	100	250

(i) The weight of fly ash, and

(ii) The distance of the dust level below the top of the collecting bin immediately it was removed from the pilot precipitator and after settling had ceased.

From these measurements and a knowledge of the bin's dimensions, the density of the ash was determined.

In one series of pilot scale tests it was observed that higher efficiencies resulted in lower bulk density. This was thought to be due to the hollow spheroidal form of the small particles which occur in greater proportion under conditions of high efficiency.

(c) Flow properties: In the normal operating temperature range of electrostatic precipitators, the fly ash flows freely and no "holding up" normally takes place. It is generally thought that this is also true for much lower temperatures. However, some cases of the ash not flowing freely have been reported and it is now usual practice for heaters to be fitted to the hoppers.

2.4 Resistivity (19)

The in-situ resistivity of the fly ash at the normal temperatures encountered in conventional electrostatic precipitators is very high by world standards. Peak values varying from 10^{13} to 2×10^{14} ohm-cm have been measured using the Kevatron Electrostatic Precipitator Analyser 223. A typical set of in-situ resistivity values for a wide temperature range is shown in Fig. 2.1 for fly ash from three different coal fields. These measurements were made during an extensive pilot plant test program.

For temperatures below about 300°F, the resistivity is dominated by the surface conduction over the fly ash particles which in turn is greatly influenced by the chemical composition of the flue gas (i.e. H_2O, SO_3 etc). At higher temperatures, or in a perfectly dry atmosphere, the fly ash behaves as a semi-insulator following the Rash Henrichsen's Law.

$$\rho = A\varepsilon^{B/T}$$

If the reciprocal of the absolute temperature is plotted against the resistivity, a straight line is obtained, the slope of which gives B. Fig. 2.2, shows this plot for fly ashes from two main coal fields. This indicates that for temperatures in the 700-800°F range, the normal values for a hot side precipitator, the resistivity of the most difficult Australian fly ash is reduced to less than 10^{10} ohm-cms.

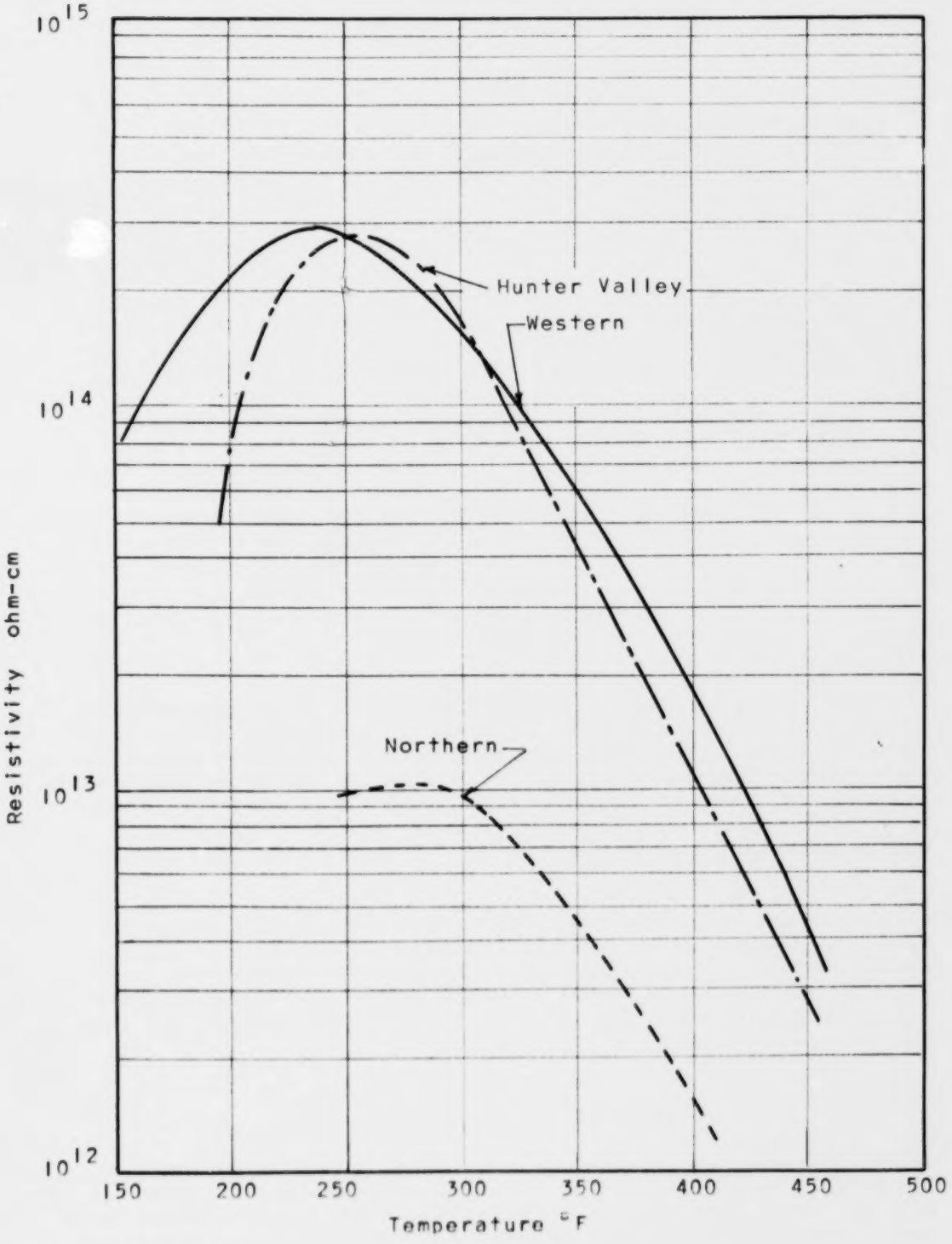

Fig. 2.1
Variation of In-situ Resistivity with Temperature

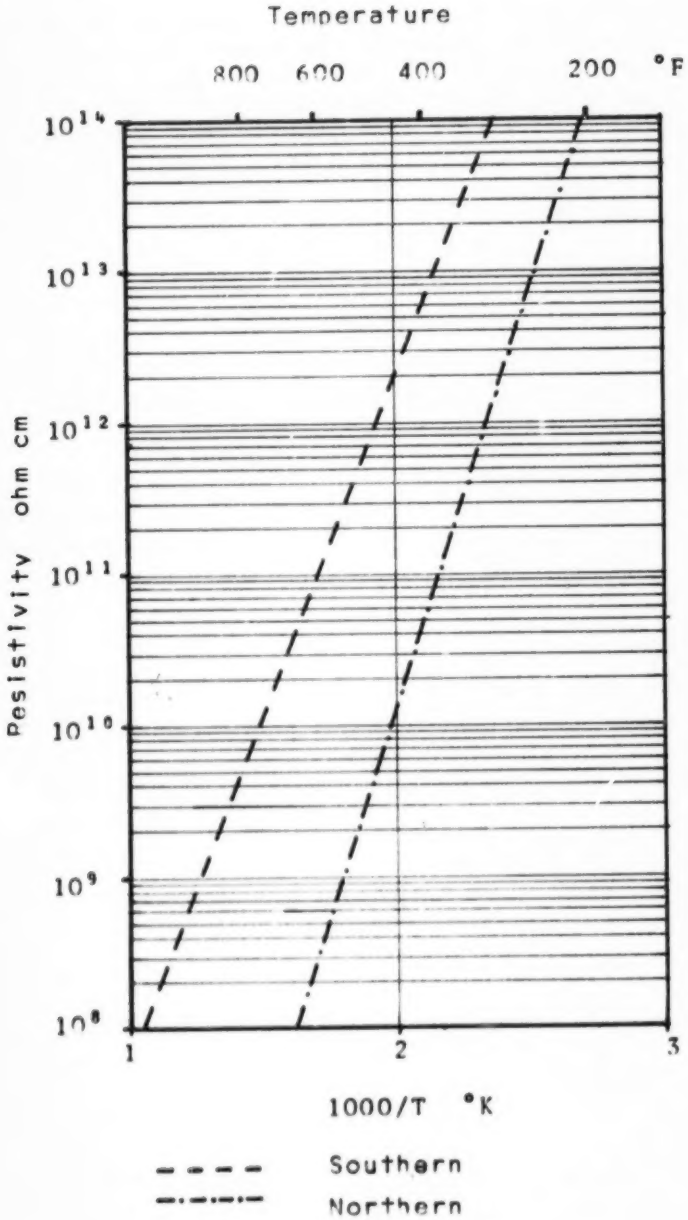

Fig. 2.2

Variation of Moisture Free Resistivity with Temperature.

Considerable care needs to be exercised in interpreting resistivity measurements and especially in comparing the values measured by one instrument with those measured by another. This caution is particularly necessary in the case of the in-situ measurements of these very high resistivity fly ashes. Extensive investigations have been made into the insignificance of some of the parameters affecting resistivity and it has been shown that, in addition to the environmental conditions, the resistivity is dependent on,

(a) compaction,

(b) particle size distribution,

(c) magnitude of the applied electric field,

(d) time of application of the applied field, and

(e) method of measurement.

The resistivity measurements recorded in this report were made at an electric field E = 1.5 kV/cm and the current read within 30 seconds of applying the measuring field.

CHAPTER 3

PERFORMANCE OF FULL SIZE ELECTROSTATIC PRECIPITATORS

3.1 Introduction

This section discusses the general specifications and performance levels of existing plate type electrostatic precipitators without flue gas conditioning, and gives some details of future plant. Some information which is of interest is either proprietary or confidential and cannot be reproduced here in any detail, but where possible, this has been included in the generalized statements and curves.

The electrostatic precipitating properties of the different fly ashes is also included. This is measured in terms of the effective migration velocity, EMV, and is calculated from the Deutsch-Anderson equation using the measured efficiency of the precipitators. The value of the EMV as determined in this manner still has to be interpreted carefully as was pointed out in Section 1.3 by making allowance for the efficiency level and temperature at which the measurements are made.

3.2 Electrostatic Precipitator Specifications (3)(5)(18)

The electrostatic precipitator manufacturers who have been successful in tendering for precipitators in New South Wales and Queensland are given in Table 3.1. The Table only lists those manufacturers who have supplied parallel plate type units since 1960, and includes the number of units together with the total capacity in MW connected to the particular manufacturer's precipitators. Existing and future plants have been included.

TABLE 3.1 - ELECTROSTATIC PRECIPITATOR MANUFACTURERS

Supplier	No. of Units	Total Capacity MW
Noyes - Research Cottrell	15	3,078
Svenska Flaktfabriken	9	2,973
Howden - Lurgi	3	760

The basic range of dimensions and operating parameters of the existing and future electrostatic precipitators are given in Table 3.2. Gas velocities tend to be lower than those commonly used in the United States, the maximum being approximately 5 ft/sec. Flue gas temperatures are generally in the range 260 to 280°F, although two large precipitators have been ordered to operate at gas temperature of 240°F. One of these units is expected to have a flue gas temperature as low as 220°F. By operating at these low temperatures, advantage is taken of the lower fly ash resistivity.

On the whole the SCA's have risen sharply from 270 in 1960 to values in the order of 400 - 600 ft^2/kcfm. The actual value depends on the type of coal being burnt, the efficiency level required and several other factors associated with operating conditions and precipitator design.

There has been no particular trend with regard to the electrical sectionalization of the precipitators. At least 3 series zones are used with the maximum number being 6. The plate area connected to a single transformer-rectifier unit varies from 9,000 to 40,000 ft^2. One manufacturer tends to use smaller plate areas in each zone than do the others. This same manufacturer is the only one to connect some of the rectifiers in the half wave mode of operation, claiming that under some conditions this gives better performance than full wave. All the electrical supply authorities regard sectionalization as important but none have formed any firm opinion with regard to the optimum arrangement. This, together with the use of half wave rectifier connections, is a matter which is generally left to the manufacturer's discretion.

Current densities are generally lower than that encountered in collecting ash from high sulphur coals. The values recorded in Table 3.2 include a significant component of back corona current so the real current which is contributing to the precipitation of the fly ash is lower than these figures.

3.3 Performance Levels (3)(5)(18)

The technique used for making efficiency measurements is in accordance with B.S. 893. Preceding the efficiency test, a traverse is made

TABLE 3.2 - RANGE OF ELECTROSTATIC PRECIPITATOR PARAMETERS

Parameter		Range
Gas and Dust		
Flue gas temperature	^{o}F	220 - 280
Gas velocity	ft/sec.	2.5 - 5.0
Moisture	% v/v	5 - 9
Inlet dust burden	gr/ft^3	5 - 11
Carbon in Ash	%	0.8 - 9.0
Particle size 50%	μm	9 - 28
Electrodes		
Collecting plate height	ft	24 - 40
Aspect ratio		.55 - .90
SCA	$ft^2/kcfm$	260 - 600
Discharge electrode construction		Frame and suspension
Discharge electrode shape		Wire, spiral wire, barbed and star.
Electrical		
No. series electrical zones		3 - 6
Plate area per zone	ft^2	9,000 - 40,000
Rectifier connections		F. W. and H. F. W.
Rectifier voltage rating	kV	60 - 70
current rating	ma	230 - 960
Normal operating current density	$\mu a/ft^2$	8 - 23
Control: system		Manual and automatic
method		Spark rate, voltage and current limit.

The values given in this table do not necessarily give the extreme values obtained in practice but rather indicate the typical range over which these parameters vary.

with pilot tubes to determine the flue gas velocity distribution in the duct. The sampling probe is then placed in the duct and the flue gas is extracted isokinetically. The particulate is collected by a Whatman's seamless thimble located in the probe but external to the duct. The flue gas sample passes through a condenser to a metering orifice, gas meter and pump. The condensate is measured at the completion of each test and is used to calculate the moisture content of the gas. The metering orifice is used to keep sampling velocities at their precalculated isokinetic value as determined from the velocity traverse.

The filter thimbles are carefully removed from the holder and the dust deposited in the probe brushed out and added to the dust in the thimble. The thimble is then placed in a drying oven for one and a half hours and dried at 170°F, after which it is placed in a desicator for 20 minutes before weighing. The efficiency measurement is made by concurrently measuring both the input and output flue gas dust burdens. Where possible, the usual practice is to measure the efficiency of each separate gas passage and the effective efficiency then calculated. During each series of tests boiler conditions are held constant and the significant parameters monitored.

The performance levels of the full size electrostatic precipitators burning coals from the different seams are shown in Fig. 3.1 and 3.2. The electrostatic precipitation performance level does not fall on a well defined line but tends to lay in a band. This has been determined from tests on full size and pilot precipitators. The variations within the band are dependent on a number of factors, one of the most important being the variation of the chemical composition of the coal. For any one coal field there are variations from one seam to another, and even in one seam, differences occur from one mine to another.

Superimposed on these bands are the guaranteed efficiencies of existing and future precipitators burning coal from these coal fields. These figures may be regarded as being indicative of the performance level of each electrostatic precipitator and take into account the mine from which the coal comes and a number of other factors. At the acceptance tests, most of the precipitators performed better than the guaranteed figure and in some cases, significantly exceeded them.

Fly ash from the Wongawilli coal seam is the most difficult to catch in an electrostatic precipitator. The precipitator efficiency level given in Fig. 3.1 is a typical value and shows that the EMV is less than 3 cm/sec. With flue gas conditioning however the precipitator performs at a satisfactory level.

For some precipitators lower efficiency values have been measured after the units have been in service for a period of time. This decay is probably due to dust build up on the electrodes, loss of discharge electrodes due to breakages, electrical zones being out of service, incorrect adjustment of the automatic control and a general deterioration of the mechanical components and alignments. It is not uncommon for the effective drift velocity to fall to at least 75 percent of its accep-

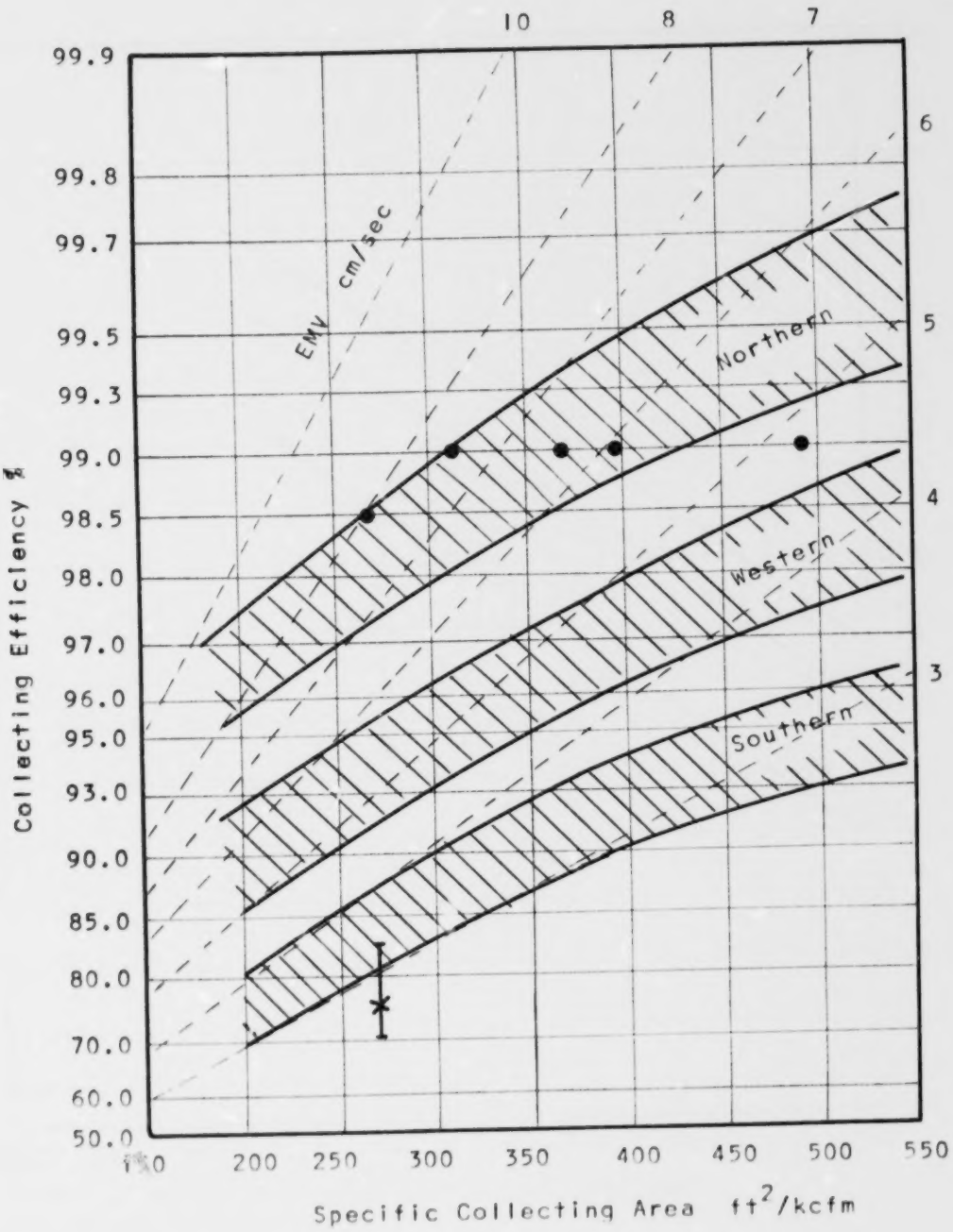

Fig. 3.1
Electrostatic Precipitation Performance Levels of Fly-ash from NSW's Coals.

o Specified efficiency and SCA (Northern)

Typical Performance Level (Southern)

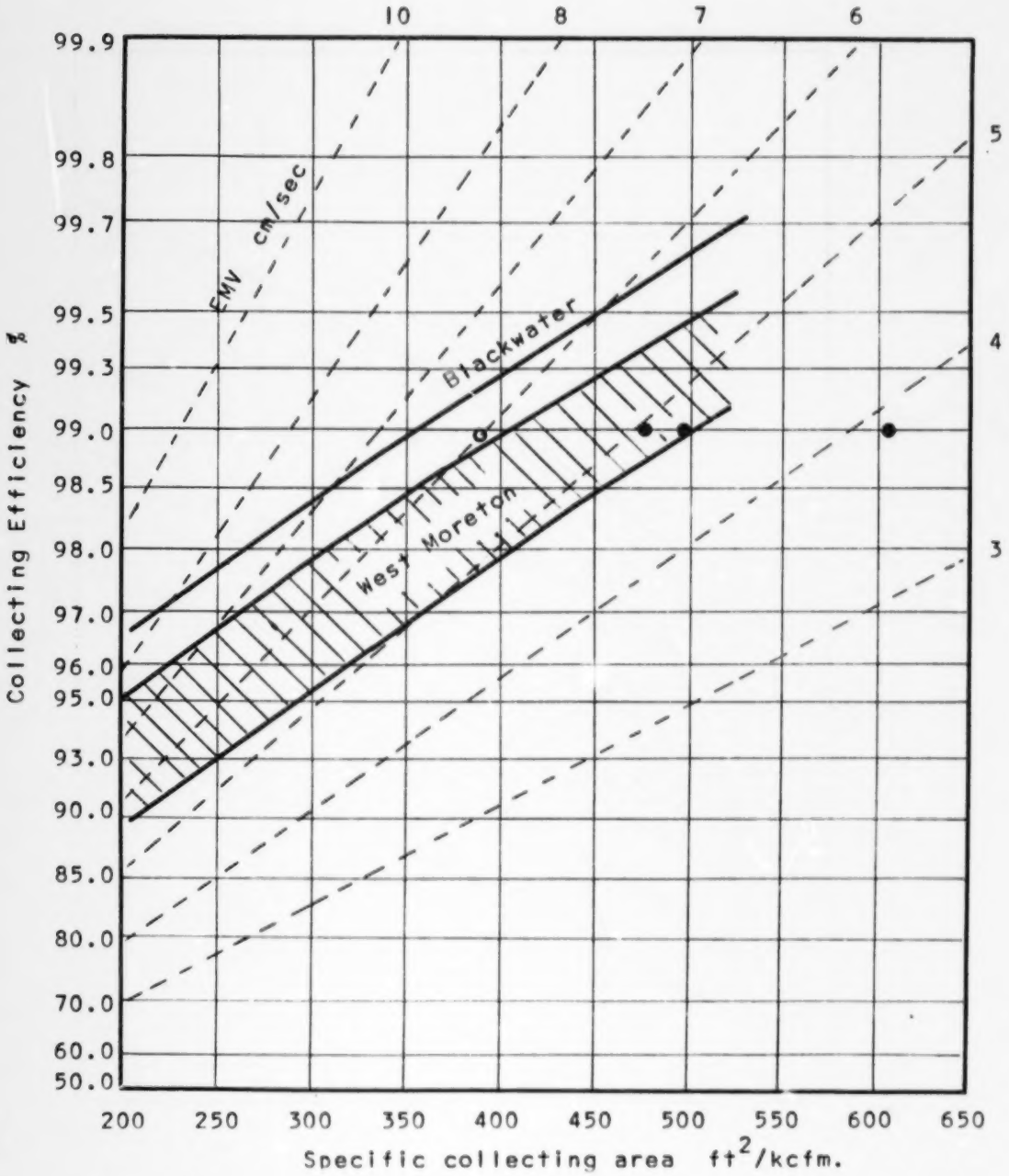

Fig. 3.2
Electrostatic Precipitation Performance Levels of Fly-ash from Queensland's Coals.

● Specified Efficiency and Design SCA.(West Moreton)

o Specified Efficiency and Design SCA.(Blackwater)

tance test value. The efficiency of some makes of precipitators seems to decay more rapidly than others and is influenced by changes in boiler conditions. It is quite likely that precipitators collecting high resistivity ash are more sensitive to these factors than precipitators collecting low resistivity ash. No statistical evidence however, is available to confirm this.

3.4 Operating Experience (3)(5)

In this section some observations are made concerning the general experience in collecting high resistivity fly ash.

(a) Rapping:

The magnitude of the force holding the fly ash to the electrodes is a function of the effective resistivity of the deposited layer and the corona current density. The corona current densities in precipitators collecting high resistivity fly ash are usually lower than those for high sulphur coals by a factor of 2 or 3, but the resistivity is 2 to 3 orders of magnitude higher. The net effect of this is that the adhesive forces holding the fly ash to the plate are very much higher than for the low sulphur coals and large forces are required to dislodge the dust from the collecting plate.

The ECNSW has carried out extensive tests on measuring the acceleration forces on different collecting plate configurations and has concluded that a minimum acceleration of 60 g in the transverse direction (i.e. normal to the plate) is required to dislodge the fly ash. In practice, transverse accelerations from 100 to 400 g have been measured at some locations on modern precipitator plates. Some of the older installations have accelerations well below the 60 g value.

There does appear to be some correlation between poor performance and the magnitude of the acceleration forces. In one instance, a modern precipitator's performance tends to deteriorate with time in service and it is considered that this may be due to the generally lower acceleration levels associated with this plant. In the case of one of the older plants, where the acceleration forces are low, it has been necessary to introduce periodic washing of the collecting plates with water in order to prevent excessive build up of the dust layer.

One consequence of the higher acceleration requirements, is that the rapping forces must be higher than normal. Initially this caused considerable maintenance problems and in some cases considerable structural damage has occured. In all the plants however where this trouble occured, modifications were made to rectify the faults and reliable performance obtained.

The rapping frequency for the collecting plates varies from one manufacturer to another. It seems possible to classify the systems used into three distinct categories,

(i) Continuous rapping at constant frequency for all electrical zones. Each plate section receives a single rap at regular time intervals of about two minutes irrespective of the electrical zone.

(ii) All the plates in the one zone are rapped together, or consecutively in a short time period, with a frequency that varies from one zone to another. The usual practice is to rap the inlet zone most frequently and the center and outlet zones less frequently. A typical rapping period for the three zones would be 15/30/60 minutes.

(iii) A combination of the above two. The plates in one zone are all rapped at the one frequency but are phased to give continuous rapping, i.e. equal time intervals between the rapping of each plate section in the zone. The zone rapping frequencies are similar to those used in (ii) above. This system has the advantage of reducing at any given time, the visual obscuration of the smoke plume during the rapping period. It is also likely that this system also reduces the total emissions.

The optimum rapping frequency and magnitude has to be found by experiment for each particular plant and fly ash. An important part of tuning a precipitator is the correct adjustment of the rapping. The general experience in the ECNSW seems to indicate that less frequent rapping probably gives better results than a series of frequent raps.

The policy of all the electric authorities concerned in this survey is to ask for a minimum acceleration of 60 g in their specifications. Because of the ECNSW's extensive testing programme they are able to anticipate with good accuracy the magnitudes of acceleration to be expected for standard collecting plate construction. If there is any uncertainty, acceptance tests are asked for in order to check the manufacturer's claims.

(b) Discharge Wires:

One of the principal causes of electrical zone unavailability is the grounding of the high voltage discharge electrode system due to wire failure. The effect of this is partly reduced by providing a number of zones which may be electrically isolated and by providing isolating dampers in each gas path which enables a faulty zone to be repaired without shutting down the boiler.

Most European manufacturers provide frames for holding the discharge wires. These electrodes may comprise a solid rod or twisted square securely welded top and bottom, or it may be a spiral wire held in tension. The only United States manufacturer who has modern precipitators installed, uses the single long wire held in tension by a weight. Both types of support construction have been in service for reasonable periods of time and it has not been found that one system has any marked advantage over the other. Electrodes in frames have a good operating record although in some of the older plants, the frames have

warped a little. One advantage of this construction is that in the event of a discharge wire breaking it does not always cause the electrical zone to be shorted out. Operation can often be maintained although sometimes at a reduced voltage. It is likely that better alignment is possible with the single suspended wire although difficulties have been found with the movement of the bottom holding frame. Anti-sway insulators have been installed to remedy this.

The discharge electrodes of the two European manufacturers differ from the practice of the United States manufacturer. One uses spiral wires and the other a mixture of barbed and star shaped electrodes. No information on their relative merits is available for release.

(c) Electrical Characteristics:(21)(23)(24)

Because of the high resistivity of the fly ash, the electrical characteristics of the Australian installations differ somewhat from those units collecting ash from high sulphur coals. They are characterised by,

(i) Low applied voltages,
(ii) Existence of back corona,
(iii) High ineffective currents.

A typical set of voltage-current characteristics is shown in Fig. 3.3. The initial part of each curve is the normal corona characteristic suppressed to some extent by the voltage drop across the dust layer. At point 'A', back corona is established in the layer on the collecting plate and a positive ions flow back to the discharge electrode. This component of the current flow does not contribute to the collection of the particulates but has a deleterious effect. In some instances, this component may comprise 60 percent of the total current flowing.

Sparking does not usually occur at the onset of back corona as may be seen in the figure. It appears that at the onset of back corona, the voltage gradient in the air gap is not sufficient to propagate a spark. As the back corona increases, the positive charge in the gap must so modify the field as to cause sparking.

The type of automatic control used varies with the manufacturer. It may be completely dependent on the spark rate, it may be designed to operate at the maximum voltage below sparking or it may have voltage, current and spark rate limits. In the latter case, the current limit usually determines the operating point. Under some operating conditions all these methods of control have some limitations. If the control is based on the spark rate alone, it is possible for a precipitator to operate at less than its maximum voltage as shown by point 'B' in Fig. 3.3. This occurs when the resistivity is particularly high and the corona d.c. voltage falls off with increased current flow. However, current limit control may also not give optimum conditions for all operating modes. If the current limit is set at level 'C', the resultant voltage level of the precipitator collecting the lower resistivity fly ash is not at its optimum value and may be raised with

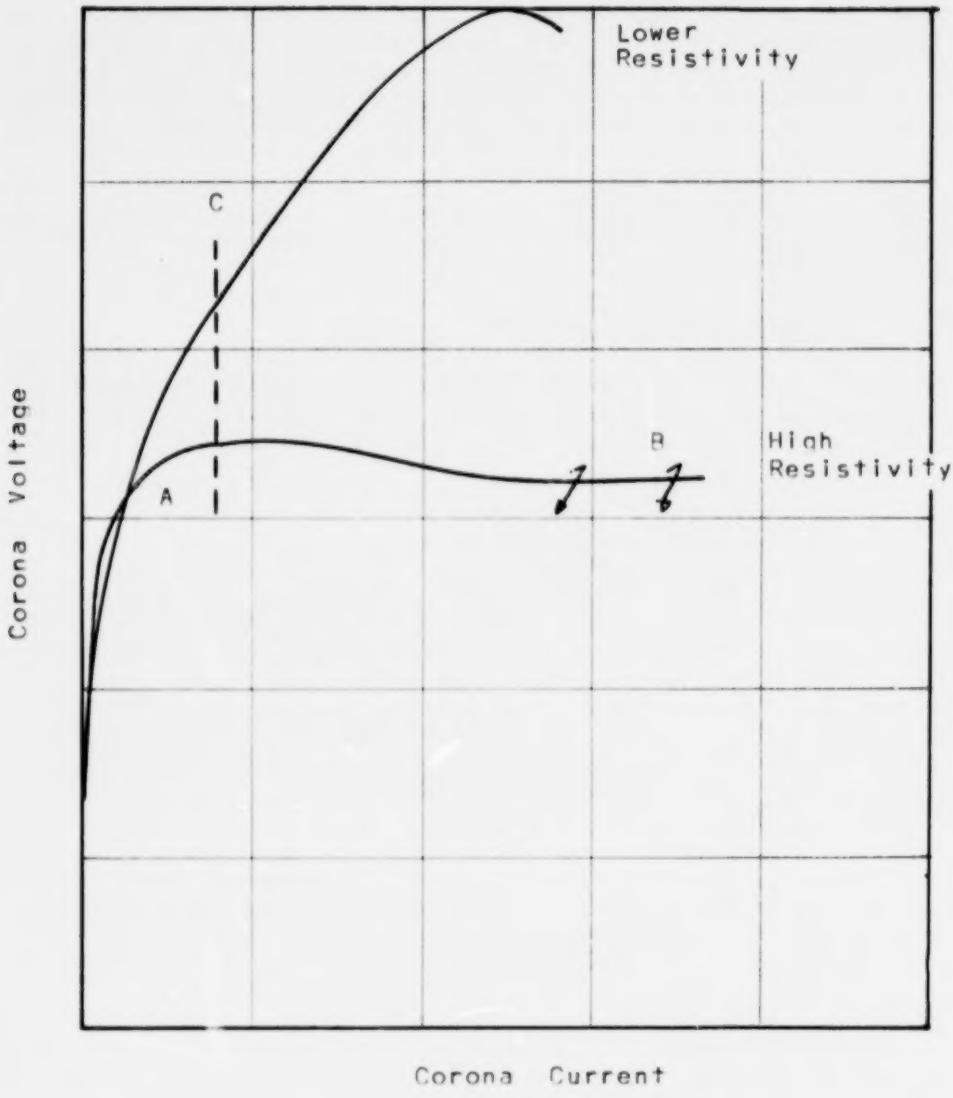

Fig. 3.3

Typical Shape of the Corona Voltage-Current Characteristic for the Inlet Zone.

advantage. The current control setting in this case would however, be satisfactory for the higher resisitivty fly ash.

(d) Mechanical Collectors:

In the older plants where mechanical collectors were used, they preceded the electrostatic precipitators. As the result of a series of pilot tests with the inlet before and after the mechanical collectors, it was concluded that the precipitating characteristics of the ash reaching the electrostatic precipitator after the mechanical collector was altered to such a degree as to materially reduce the overall efficiency. As a result of this experimental evidence and other investigations, it was decided to use only electrostatic precipitators. This policy has been implemented since 1960.

(e) Outages and Maintenance:

An electrostatic precipitator may be put out of operation for any one of a number of different reasons. Neither the type of fault nor their frequency indicates that the collecting of high resistivity fly ash introduces any special maintenance problems.

Table 3.3 gives the outages that occured for all the modern precipitators during a 3-month period. The precipitator availability varied from 85.4 to 99.5 percent of the boiler service hours over this period.

TABLE 3.3 - PRECIPITATOR OUTAGES

Fault Type	No.
Discharge electrode short	6
Rectifier or control circuit	27
Frame or structure failure	6
Dust level in hoppers	1
Collecting electrodes control circuit	9
Rapper failure	19
Miscellaneous (incl. alarms)	15

(f) Influence of Operating Conditions:

It has been observed that the performance level of some precipitators is dependent on operating conditions. In one case, the precipitator does not reach maximum efficiency until it has been in service for a period of seven to eight days, and its performance falls off rapidly with any variation in the boiler conditions. These precipitators can be tuned to give very good performance levels providing boiler conditions remain stable. On the other hand, other precipitators appear to be less sensitive to these variations. The reasons for this have not been resolved.

(g) Pipe Type Precipitators:

Pipe precipitators were installed at four of the earlier power stations. On the whole their performance in terms of EMV is well below that of the modern plate precipitators. This is probably due to the difficulty in obtaining sufficiently high accelerations during rapping because of the rigid clamping of the pipes at the top end, and that they effectively only have one series zone. New rapping methods were designed by the ECNSW and improved performance obtained. It is considered that this type of precipitator is generally unsatisfactory for handling the large volumes of gas necessary at modern plants and for collecting high resistivity fly ash. No pipe precipitators have been installed since 1961.

3.5 Variations of EMV with Sulphur Content of Coal

Fig. 3.4 shows the variation of the EMV, as determined from the full size precipitators, with the sulphur content of the coal. Where possible the values recorded are calculated from actual measurements but in some cases design figures are included. No adjustment has been made for the different SCA's and temperatures at which measurements are made. There is no obvious correlation between the electrostatic precipitating properties of the ash and the sulphur content of the coal. The two most difficult fly ashes to collect, Southern and Western, do not have the lowest sulphur content. It is quite possible that this may be a characteristic of all coals with a sulphur content below one percent.

3.6 Hot Side Precipitators

Certain manufacturers have offered precipitators designed to operate ahead of the air heaters so as to take advantage of the higher temperature to reduce the resistivity of the fly ash. The resultant increase in EMV is offset to some extent by a number of factors, of which the increased volume of flue gas the precipitators have to handle, is one of the most important (29).

Pilot precipitator tests have been conducted for temperatures from 170°F to 650°F and have shown that the EMV is considerably improved at both the lower and higher ends of this temperature range. For the Australian fly ash, it is considered that at this stage of precipitator design knowledge, more desirable to rely on the lower temperatures to reduce the resistivity rather than the higher temperatures.

It is considered possible that experience may show hot precipitators to be more uniformly efficient than their low temperature counterparts because the resultant resistivity is dependent only on temperature and not on the moisture or other constituents of the flue gas composition. More development work and basic investigation is required in this area.

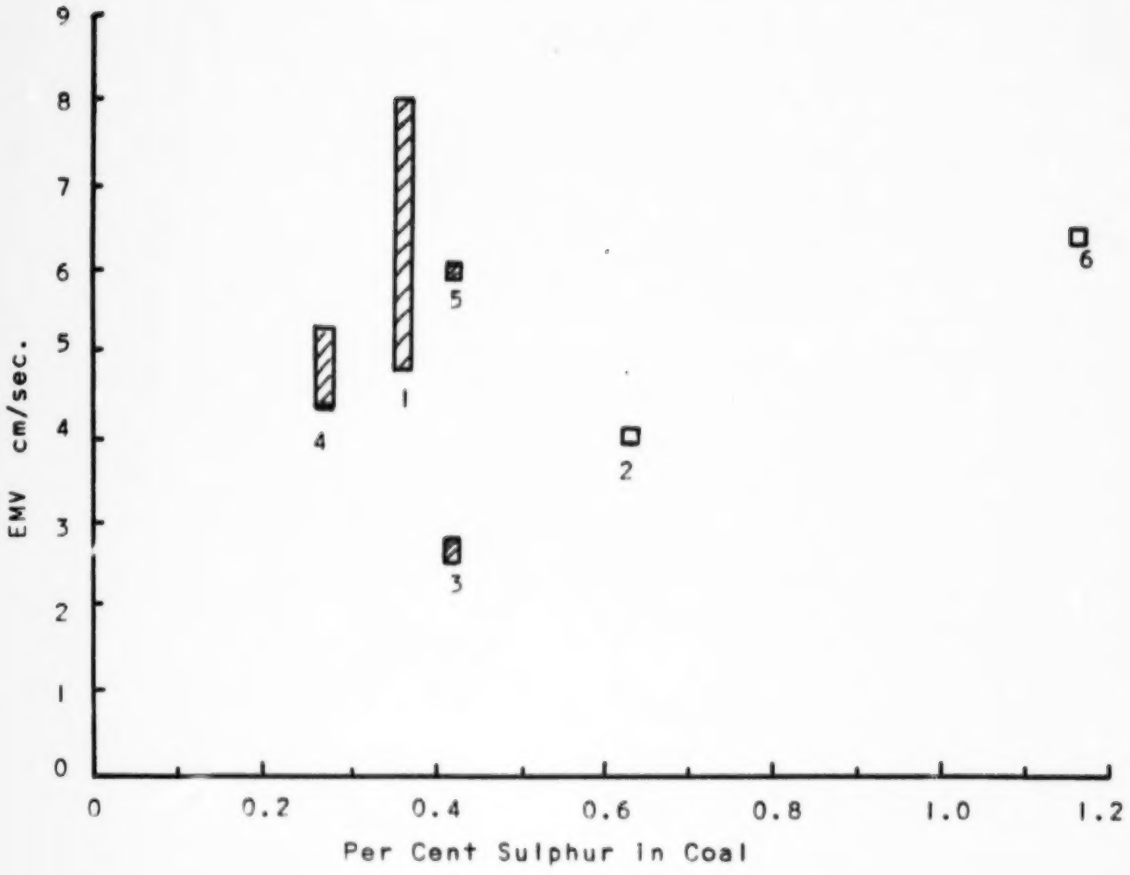

Fig. 3.4
Variation of EMV with Sulphur Content in Coal.

▨ Test figures

□ Design figures

1.	Northern	SCA = 280-520	T = 260-280 °F
2.	Western	SCA > 500	T = 240 °F
3.	Southern	SCA = 275	T = 276 °F
4.	West Moreton	SCA = 450-530	T = 260-270 °F
5.	Blackwater	SCA = 490-520	T = 300 °F
6.	Bowen	SCA = 250	T = 300 °F

CHAPTER 4

PILOT SCALE PRECIPITATOR TESTS

4.1 Introduction

Up to the late 1950's, the electrostatic precipitators installed at the power stations of the ECNSW had been uniformly unsatisfactory in collecting fly ash from the low sulphur coals. From 1959 the ECNSW indicated to manufacturers of electrostatic precipitators that it would be necessary for them to demonstrate the effectiveness of their equipment by means of pilot plant tests before serious consideration would be given to its purchase. Since then a large number of pilot scale tests have been carried out by a number of manufacturers (Research Cottrell, Svenska Flaktfabriken, Howden-Lurgi, Lodge-Cottrell, Simon Carves, Sturtevants and Western Precipitation). These tests were initially conducted at one of the older power stations and in some cases the coal to be tested was imported and burnt under controlled conditions. Later on, pilot tests were conducted at the larger modern power stations.

The range of the main parameters of three important pilot precipitators used in tests over the last 12 years is given in Table.4.1. It is considered important that the electrode sizes and spacing be the same as in the full scale precipitators and that they should comprise a number of series electrical zones.

TABLE 4.1 - PILOT PRECIPITATOR PARAMETERS

Precipitator Parameter		Range
Collecting area	ft^2	576 - 825
Electrode spacing	in	9 - 10.75
Plate height	ft	6.5 - 8
Treatment length	ft	12 - 25.5
Parallel gas passages		1 - 4
No. of rectifiers		1 - 3
No. of series zones		2 - 3
Rectifier connection		H. W. and F. W.
Gas velocity	ft/sec	1 - 5

4.2 Factors Affecting the Interpretation of Pilot Precipitator Tests (2)(5)(6)

It is considered that any test series with the pilot precipitator should include tests at the specific collecting area and temperature at which it is proposed to operate the future full size precipitator. Although it is possible to extrapolate the results to some extent it does introduce additional elements of uncertainty and should be avoided if possible. Even when these conditions are satisfied there are still a number of factors which may cause the performance of the pilot precipitator to differ from that of the full size units. Some of these are briefly discussed below.

(a) Gas velocity

Because of the overall dimensions of the pilot precipitator, the gas flow velocity is usually considerably lower for a given SCA than it would be in a full size unit for the same SCA. The lower gas velocity in the pilot plants probably reduces the re-entrainment and scouring of the dust off the plates and may therefore produce a more optimistic result.

(b) Gas and Temperature Distribution

Because of the smaller geometrical dimensions in the pilot precipitator it is easier to obtain better gas and temperature distribution than is often obtained in the full scale units.

(c) Alignment of Electrodes

Any misalignment of the discharge electrodes reduces the maximum voltage that can be maintained without excessive sparking occuring. In the pilot plants where the length of the electrodes is less and their number much smaller than in the full size plants, it is much easier to obtain optimum operating conditions.

(d) Leakage and End Effects

Any leakage of air into an electrostatic precipitator will have an adverse effect on its performance as this increases the volume of gas passing through it.

Because of the high ratio of jointing length to total exterior area, leakage is more of a problem in pilot precipitators than in the full scale units. In addition, since the plates are relatively short the movement of gas around the outside and over the top and bottom can be disproportionately large in a pilot precipitator. The net result of these effects is to produce a less favourable performance than that of the full size plants.

(e) Rapping

Since the collecting plate area of the pilot precipitators is small, it is relatively easy to provide adequate rapping facilities and no problems are generally experienced in removing the deposited fly ash. This can only be achieved in full scale precipitators by having well designed rapping systems carefully tuned to give maximum performance. Hence it may be assumed that in this respect the perform-

ance of the pilot precipitators is probably more favourable than for the full size units.

(f) Particle Size

It is possible that the particle size distribution at the plant at which the pilot precipitator is being tested may differ from that produced at the future plant. This has occured in N.S.W. At two of the older power stations, the size distribution of the ash from the Great Northern coal seam is in the range 7-14μm whereas at the modern plants the actual size distribution is 19.0-27.5μm. In this case, the pilot precipitator would be expected to give a more pessimistic result than the full scale precipitator.

(g) Electrical Energization

Several different approaches have been adopted for setting the electrical conditions of the pilot precipitators. These are,

(i) Adjust the voltage to give light sparking.

(ii) Set the voltage to the maximum value that can be maintained without sparking.

(iii) Adjust the control to give a constant current density.

The method of voltage control used varies with the manufacturer and is related to the philosophy each adopts for their control system in the full size precipitators. The ECNSW has had tests carried out in all the three modes mentioned above. It has been observed that when the pilot precipitator is operated in the light sparking mode, its efficiency is temperature dependent but this is not always the case when operated in the constant current mode.

It is generally thought that because of the much larger area connected to one rectifier in the full size precipitators, there is an increased probability of sparking and other abnormalities. This means that the electrical conditions in the pilot precipitators will generally be more favourable than in the full size precipitators and so will give a better performance level.

(h) Coal Variation

An additional factor which makes correlation with full size precipitators difficult is the variation in the coal being burnt during the life of the power station. Variations in the precipitating properties of ash from the coal in a given seam occur from one colliery to another and recently it has been observed that changes also occur over a period of time in coal from the same colliery. This makes it very difficult to be sure that the sample used in the pilot precipitator tests is representative of what is going to be used in the full scale plant.

4.3 Scaling Factor

Altogether there are a number of factors which must be considered in scaling the results from tests obtained on a pilot precipitator to

that of a full scale unit. If the effect of each parameter is indicated by a constant factor K, then it is possible to write the simple equation,

$$\omega_{FS} = \omega_{pp} K_T$$

where $K_T = K_1 \times K_2 \times K_3 \ldots K_n$

ω_{FS} = EMV of full size precipitator

ω_{pp} = EMV measured by the pilot precipitator

The constants K_n may be either greater or less than one, depending on which parameter they are associated with. The value of K_T will vary from one precipitator to another. One manufacturer uses a $K_T = 1$ while others use values less than 1.

4.4 Test Arrangement (11)(14)(22)(26)

Generally, flue gas take off points for the pilot precipitator are provided before and after the air heater to enable high temperature tests to be carried out. The final temperature control of the flue gas for the unit is obtained by means of a heat exchanger and electric heaters located in the inlet duct. The pilot precipitator casing is fitted with heating elements to assist in keeping a constant temperature through the stages. The actual temperature range varies from one test location to another but typically ranges from 170 to 600°F. A disc and two perforated plates are installed at the inlet to the pilot precipitator in order to provide reasonable gas distribution across the precipitator.

The dust sizing and burden at the inlet to the pilot plant in all tests were in reasonable agreement with that measured in the main duct.

The efficiency of the pilot plant is determined by isokinetically measuring the input and output duct mass flow loadings by the method described in Section 3.3. An alternative method which is found to be satisfactory is to compare the catch with the outlet burden.

4.5 Typical Daily Test Routine (11)(14)(22)(26)

Normally the boilers are kept in service overnight on reduced output but during the testing period the boiler operates at rated load

with a constant setting for the fuel/air ratio. Soot blowing is carried out before testing starts each morning and quite often between tests so as to maintain metal temperatures within acceptable operating limits.

Before each test, the pilot precipitator is operated at the desired condition for at least half an hour. When the voltage and current readings indicate that constant conditions are reached, the test is started. Three one hour tests are carried out for each set of conditions, and up to six one hour tests are carried out in a day. The voltage-current characteristics are measured once for each set of test conditions immediately after the last test is completed.

The actual test programme usually includes:-

(a) A series of tests on the main coal covering a wide temperature range. For these tests the SCA was kept constant.

(b) Tests at the design back end temperature of the new plant with different values of specific collecting area using the main test coal.

(c) Test (b) repeated for other coal samples.

The electrical conditions are normally kept constant for each set of tests, although in any given test program the pilot precipitator is often operated in both the light sparking and constant current mode.

4.6 Relationship to Full Size Precipitator Performance

The fly ash from the Great Northern, Bayswater, Wongawilli, West Moreton and the Main Lower Blackwater coal seams have been tested by both pilot scale precipitators and by adequately designed plate type full size units so that it is possible to obtain some indication of how well the pilot precipitators model the full scale units.

The fly ash from the Great Northern coal seam has been extensively tested with pilot electrostatic precipitators manufactured by Research Cottrell, Lurgi, Svenska Flaktfabriken and Western. The earlier tests were conducted at the older power stations but since the construction of modern plants, comparative pilot precipitator tests have been carried out at these stations. Figs. 4.1 to 4.3 give a summary of these results and compares the EMV's as calculated from the pilot and full size precipitator tests. The comparison is made at an SCA of 350 ft^2/kcfm and for a temperature range of 260 to 290°F.

Fig. 4.1 records the results of tests on the Great Northern coal seam. Column C gives the EMV of the same pilot precipitator operating at two of the older power stations burning Great Northern coal. They indicate that little variation exists in the value of the EMV as the result of burning the same coal in two different boilers. Point B is the value determined from the tests with a second pilot precipitator at one of these older power stations. After the construction of a modern station, the pilot precipitator, used to measure results in Column C, was set up at this station in order to check whether its

performance would agree with the earlier tests. A wide range of results were obtained but the mean value of the EMV at the reference SCA is shown by point A in Fig. 4.1. The improved performance over that obtained in the earlier tests indicated by Column C may in part be accounted for by,

(a) Difference in mean particle size. At the modern plant this is in the order of 22μm where as at the older stations the size was closer to 12μm.

(b) The temperatures at modern plants (265$\pm$5°F) are lower than those at the older plants (286°F and 280°F).

On these two points alone, the test results at the modern plant should give a more optimistic result than given at the other two power stations.

The EMV's of the full size electrostatic precipitators are indicated by Column D in Fig. 4.1. These values are calculated from the acceptance tests of precipitators operating at SCA's from 250 to 530 ft /kcfm; the lower EMV's being associated with the higher SCA's. In order to make a more realistic comparison at the reference SCA, the EMV's at the lower values of SCA need to be decreased and at the higher SCA's, they need to be increased. The writer has made an estimate of what these values should be and is shown by Column E.

Column F gives the EMV range of the nominal performance band of the Great Northern coal seam.

It is generally held by the ECNSW engineers that the pilot tests for their own coals give much better quantitative information than might at first be concluded from Figure 4.1. The reason for the wide scatter of results can be better appreciated when it is realised that the tests recorded here for the Great Northern seam have been made over a 12 year period for coals mined at six different locations, fired by 10 different boilers and tested by 7 different types of electrostatic precipitators.

The Wongawilli fly ash was tested by a pilot precipitator in the early sixties and these tests indicated that this fly ash was particularly difficult to collect with resulting EMV's of 3-4cm/sec. The tests on the full scale units at Tallawarra gave results a little lower than these values. This is shown in Fig. 4.2.

At Swanbank Power Station, Queensland, both pilot and full size electrostatic precipitator efficiency tests have been made on fly ash from the Blackwater Main Lower and West Moreton coals and the calculated values of the EMV's are summarized in Fig. 4.3. The full size precipitator tests were made for SCA's in the range of 450 to 530 ft /kcfm. An estimate of the EMV for the reference SCA of 350 ft /kcfm is shown for both types of coal.

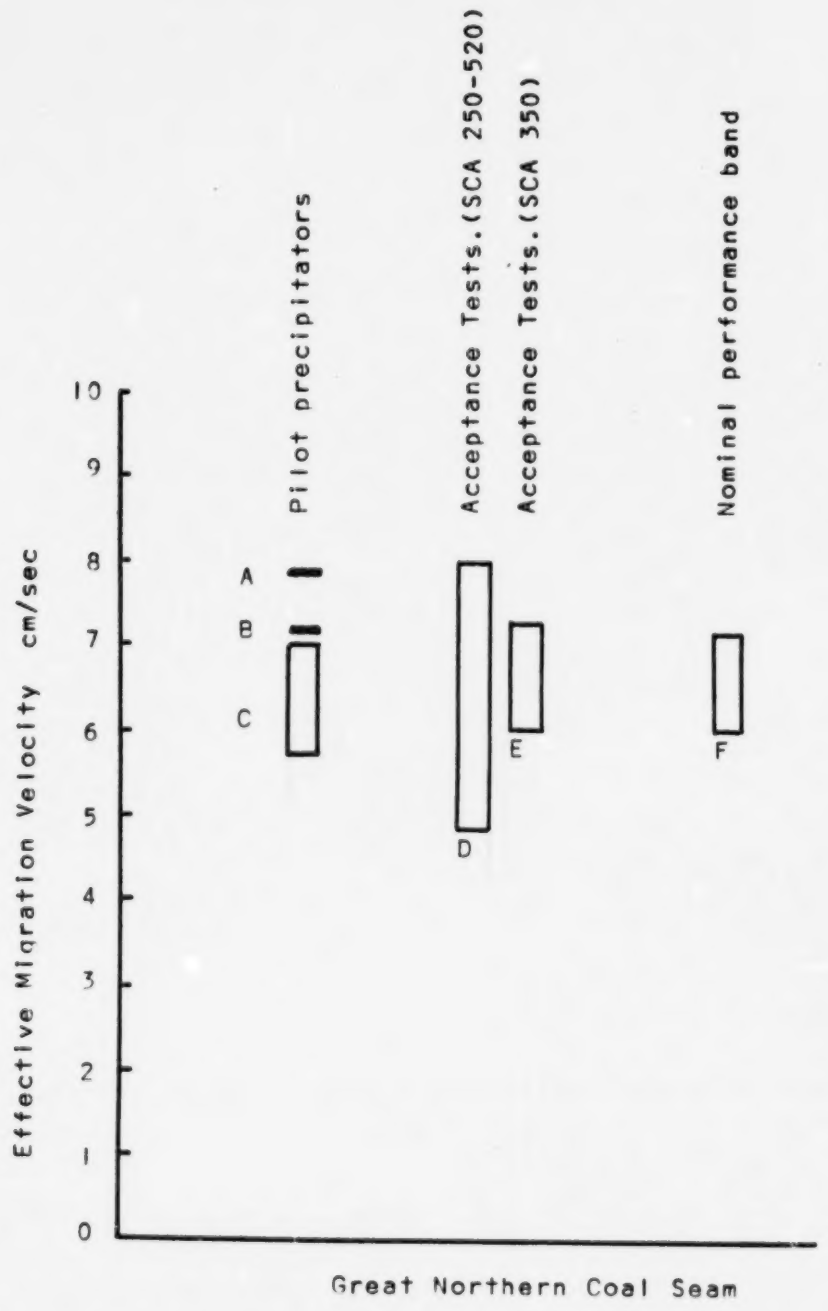

Fig. 4.1

Comparison of EMVs for thr Great Northern Fly-ash. SCA = 350 ft^2/kcfm. Temp. = 260 -290°F.

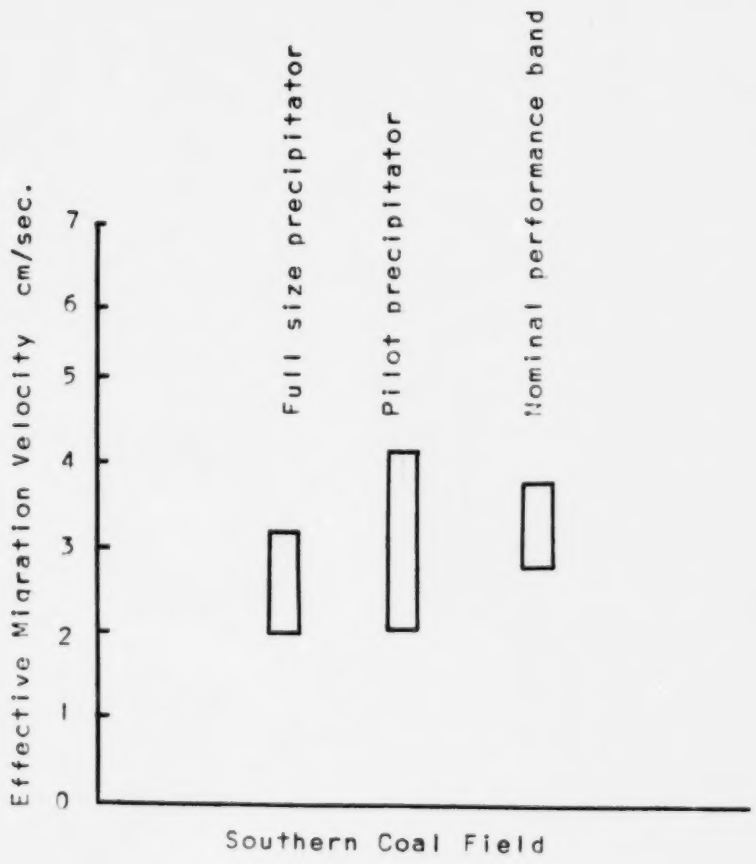

Fig. 4.2

Comparison of EMVs for the Southern Coal Field Fly-ash. SCA = 350 ft^2/kcfm.

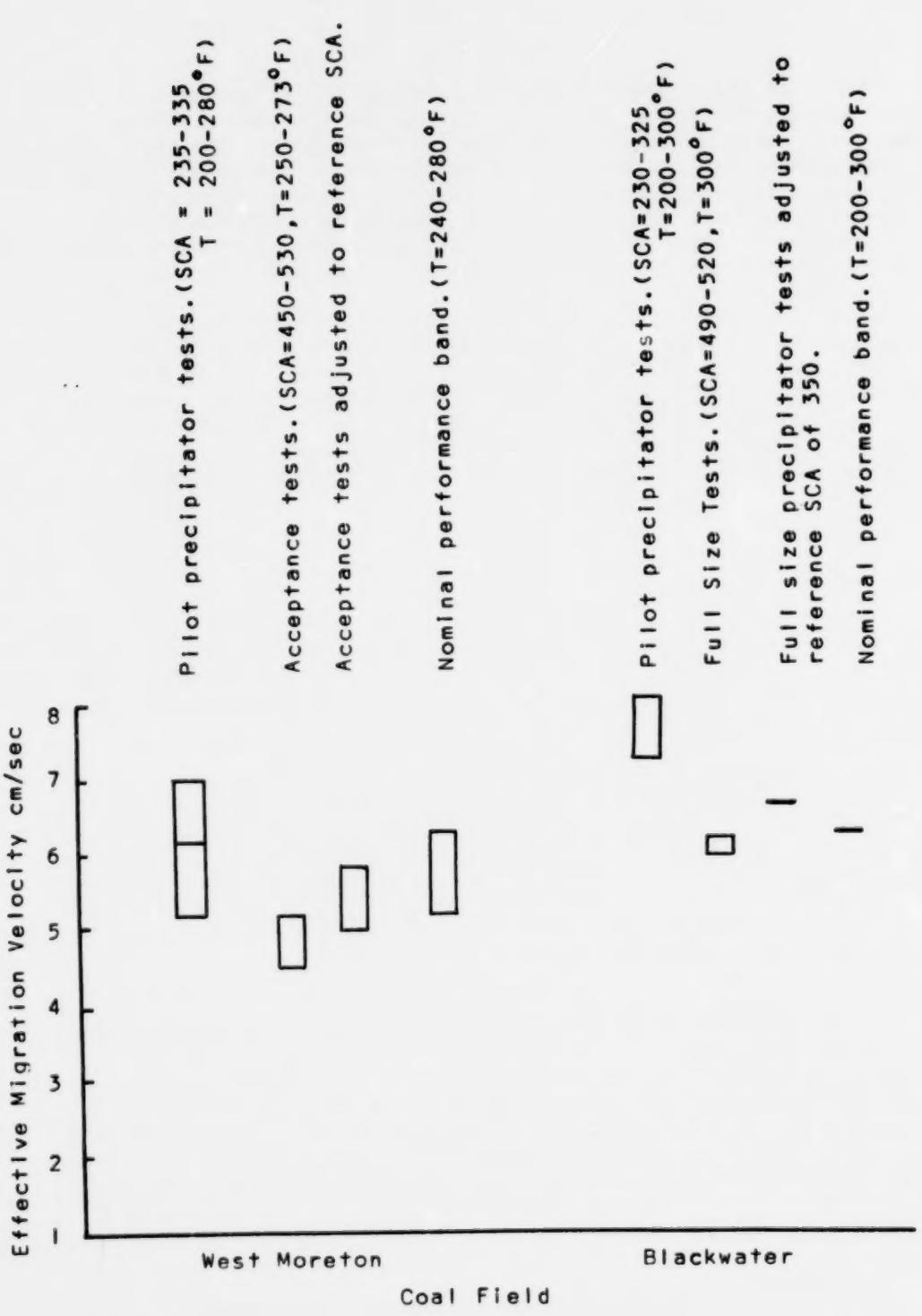

Fig. 4.3
Comparison of EMVs for West Moreton and Blackwater Coals. Reference SCA = 350ft^2/kcfm.

The pilot precipitator tests were carried out at a constant current density and not at light sparking as was the case with the ECNSW. This makes comparison some what more difficult. The tests on the West Moreton coal is probably representative as the corona voltage-current characteristics show that the precipitator was operating in the back corona mode. This was not the case for the Blackwater Main Lower coal and it seems most likely that a better level of performance could have been obtained by operating in the light sparking mode.

It is the writer's view that the pilot precipitator tests, when operated in the light sparking mode, generally give a slightly more optimistic result than do the full size precipitators. It is generally considered in Australia that, providing the same pilot precipitator is used, the test results may be used to accurately rank the precipitating properties of the different fly ashes and that a reliable scaling factor may be found to predict the effective migration velocity in future full size units.

4.7 General Data from Pilot Tests (11)(14)(22)(26)(3)

One of the secondary benefits gained from these tests is the better understanding obtained of the effect different parameters have on the electrostatic precipitation of high resistivity fly ash. Some of these have already been discussed in other publications and are only briefly referred to in this report.

(a) Flue Gas Temperature(14)

A wide range of tests have been made at different gas temperatures for the same SCA. Because the resistivity is very high it is particularly sensitive to temperature variations as is also the efficiency. A typical temperature-efficiency relationship is shown in Fig. 4.4. Some pilot tests have shown no variations in the efficiency with temperature but it is of interest to note that in these cases the precipitator has been operated in the constant current density mode.

(b) Carbon Content of Fly Ash

Pilot tests at two power stations indicate that the electrostatic precipitator performance is not significantly affected by a carbon content in the range 2 to 10%. Resistivity tests at Wollongong University College have shown that for carbon content up to 15% the dry-air resistivity is only reduced by a factor of 2, but for contents much greater than this, the resistance drops to a very low value. Once there is sufficient carbon to form a complete path through the dust layer, then the carbon determines the effective resistivity and not the high resistivity fly ash particles.

(c) Gas Velocity (3)

It is generally considered that the overall performance of electrostatic precipitators collecting high resistivity fly ash is largely independent of the gas velocity in the range 2-8 ft/sec.

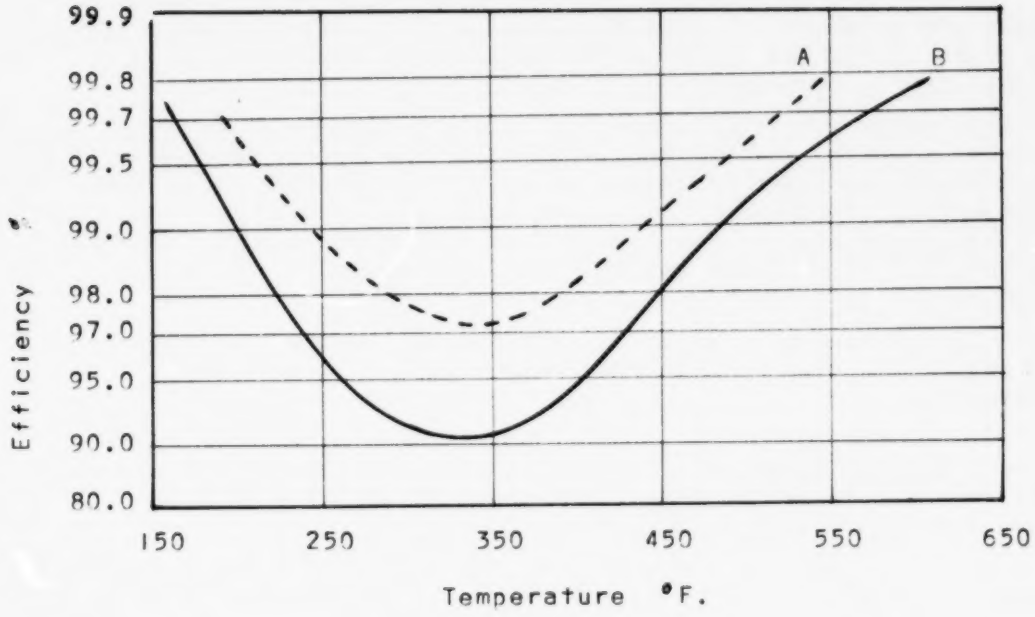

Fig. 4.4

Variation of Pilot Precipitator Efficiency with Temperature for Two Different Fly-ash Samples. SCA = 325-363.
Control: light sparking.

(d) Migration Velocity Variation with Efficiency

In all tests with pilot precipitators, the migration velocity for any given fly ash and temperature decreased in value for higher SCA's and efficiencies. A typical shape of the curve is shown by the bands in Figs. 3.1 and 3.2. The explanation for this is given in Section 1.3 and is due to the increased difficulty in collecting the finer particle sizes which is necessary in order to obtain the higher efficiencies.

(e) Sulphur

It has been traditional to expect the performance of an electrostatic precipitator to be related to the sulphur content of the coal, the higher is the resistivity of the fly ash and hence the more difficult it is to collect.

It has already been pointed out in the discussion on the full size units that the sulphur content of these low sulphur coals does not indicate the order of precipitability. This is confirmed by these pilot tests. The effective migration velocities of 11 coals from different seams are shown in Fig. 4.5 plotted against sulphur content. Most of these measurements are made with the same pilot precipitator at an SCA of 360 $ft^2/kcfm$ at a temperature of 260^oF.

In some analyses, the sulphur content was divided into pyritic and organic but even plots on this basis did not produce a better correlation.

This tends to confirm the view that the sulphur content probably gives a general indication of difficulty of precipitation when comparing a 1% sulphur coal with a 3% coal, but it is not reliable in ranking fly ashes when its content is below 1%.

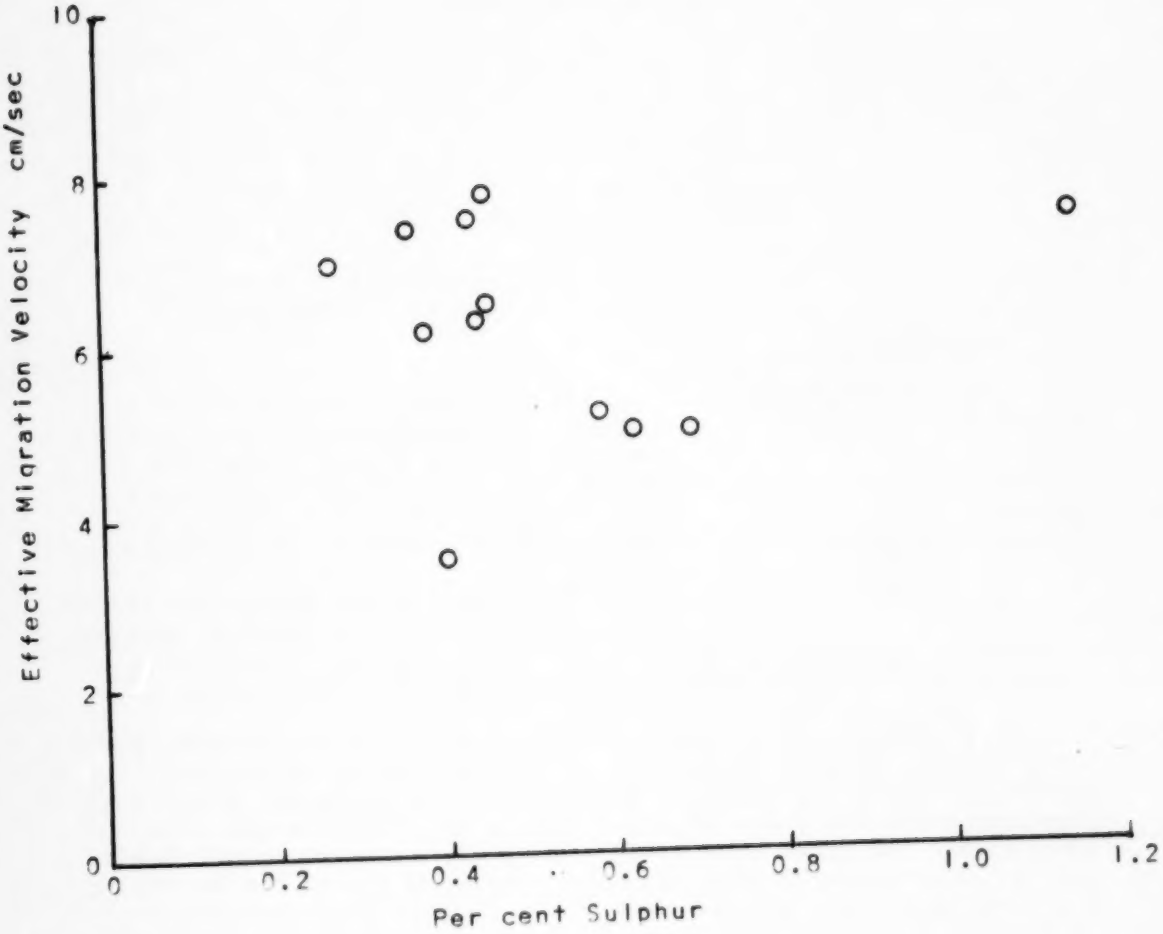

Fig. 4.5

Variation of EMV with Sulphur Content of Coal as Measured by a Pilot Precipitator. Temp. = 260°F. SCA = 360 ft^2/kcfm.

CHAPTER 5

FLUE GAS CONDITIONING

5.1 Introduction

One well known method of improving the performance of an existing electrostatic precipitator collecting high resistivity fly ash, is to condition the flue gas. The generally accepted theory is that the conditioning agent combines with water to form a higher conductivity surface over the particles thus reducing their effective resistivity. This then is accompanied by an improved performance of the precipitator.

In the ECNSW, a range of different conditioning agents have been tested, on both full size and pilot precipitators. In general, sulphur trioxide conditioning is the most successful, followed by ammonia. A number of different gas conditioning techniques have been tried.

The conditioning of flue gas is carried out for two related, but still distinguishable, purposes. (a) The first is to improve the efficiency of the precipitators so that their emissions are within the requirements of the Clean Air Act. This is applicable to the older plants which are under sized to collect ash from the low sulphur coals. (b) The modern precipitators all met the requirements of the Act during the acceptance tests but, as described in Chapter 3, it is possible under some conditions for the day by day performance to fall below the required level. Also, in the event of a zone failure, it may be necessary to close off one gas passage in order to effect repairs. Under these conditions the overall efficiency level drops. So as to maintain the required emission level under these contingencies, ammonia conditioning systems are being installed on many of the modern precipitators.

The cost of the conditioning is partly offset by the low maintenance requirement of these precipitators and the possibility of maintaining full load on the boiler during a gas passage outage.

5.2 Conditioning Agents and Methods of Injection (3)(5)(4)

One of the common methods used overseas to condition with SO_3 is to use stabilized SO_3. The liquid is vapourized, mixed with hot air and injected into the gas stream. Unfortunately this product is not commercially available in Australia and would be uneconomical to import or manufacture for a permanent conditioning system. It has however been used during the pilot precipitator test programs. The following gives a brief description of the different conditioning systems used on the full size electrostatic precipitators.

(a) Permanent Installations on Full Size Precipitators

(i) High Temperature H_2SO_4 Evaporation

The sulphuric acid is pumped into an evaporator where its temperature is raised to about 1,000°F. At this temperature the acid decomposes into SO_3 and H_2O. This is then mixed with hot air at 700-1,000°F and injected into the duct ahead of the economizer through a single pipe with graded injection holes. The whole injection system has appropriate control valves and safety devices.

To ensure continuity of injection, the acid injection system is duplicated where it is installed as the main means of conditioning. No corrosion problems have been encountered in the electrostatic precipitator or in the duct work with this method of conditioning.

The injection of the acid on the precipitator side of the air heater has been tried at one power station and it worked well on a pilot precipitator. When it was attempted to condition the fly ash for the full size precipitator it did not perform as well. It is considered that this is probably due to the poor injection system. This will be re-engineered and the system tried again in the future.

(ii) Anhydrous Ammonia

The anhydrous Ammonia is drawn from a storage tank in the liquid phase, passed through an evaporator and injected into the duct between the air heater and precipitator as close to the air heater as possible. Good distribution in the duct is obtained by using a number of injection pipes with graded injection holes.

An alternative arrangement, suitable for lower injection rates, is to draw off the ammonia in the gas phase and inject it directly into the duct. At one station, the injection system comprises three $\frac{3}{4}$" open ended pipes each of which projects different distances into the duct.

The anhydrous ammonia system is very simple, easy to operate and is free from blockages. In the initial stage of

development, it was found that a solid crust tended to build up at the outlets of the injection pipes and sometimes at points along its length. This seems to occur when the injection gas is switched off and is due to the action of leakage or residue NH_3 with the flue gas. The usual practice to eliminate this is to purge the system with air during the shut down.

Some doubts have been expressed about injecting the ammonia before the air heater as it is considered that blockages in the air heater may occur. This is still regarded as unproven and it is possible that this may not occur with the low sulphur coals.

(iii) Concentrated Ammonical Liquor (CAL).

This is a by-product of the local steel industry and is very inexpensive. Tests have been carried out using this as a conditioning agent and efficiency levels have been obtained similar, and at one station, better than that obtained with anhydrous ammonia.

The liquid CAL, after diluting and filtering, is run directly into large diameter pipes which project into the duct. These have 12 inch stand pipes which face the direction of gas flow (upwards) and the CAL liquid level is raised to about half this height. The heat of the flue gas, aided by additional heat from heaters in the pipe itself, evaporates the CAL and the resultant gas flows out of the ends of the stand pipes into the main gas stream.

Some initial difficulty was experienced with CAL at ambient temperatures below 40°F through line blockages as a result of ammonia bicarbonate crystallising out of solution. This may be eliminated by diluting the ammonia concentration to less than 15 percent. The initial cost of the product is cheap but it does require more handling than anhydrous ammonia. It is usual practice for anhydrous ammonia to be used during station start up and a switch made to CAL once temperature levels are high enough.

(iv) Water Injection.

At one power station, six water sprays each with injection capacity of 6 gals per minute, are permanently installed on a 100 MW boiler. Normal practice is to use two sprays for loads above 80 MW in conjunction with the CAL conditioning. The water injection reduces the emissions a further 7 percent below what is obtained by using CAL alone.

(b) Temporary Installations.

(i) Sulphur Burner

Elemental sulphur is burned in the presence of dry air and the resultant gas is passed over a catalyst to give a high concentration of SO_3. The system was tried in the early sixties and satisfactory conditioning was obtained. It was never used on a permanent basis because of operating and maintenance problems.

(ii) Water Injection (4).

The first extensive trials using water conditioning were carried out at Pyrmont. Water was introduced as steam from the soot-blowers, by spraying water into the combustion chamber and

spraying finely atomized water into the flue gas stream after the air heater. It was found that maximum efficiency was obtained when the water rate was 0.5-1.0 lb/1,000 ft^3 gas. If this quantity of water is injected into the combustion chamber, the heat energy used to evaporate the water would materially reduce the boiler efficiency. Injection into the gas stream was not satisfactory as complete evaporation could not be ensured and water droplets were carried over into the precipitator to cause rapid build up of ash on the electrodes.

Similar tests have been carried out at other power stations but none have been very successful except as an adjunct to ammonia conditioning.

5.3 Effect of Conditioning on Fly Ash Electrostatic Precipitation Properties (3)(4)(5)(20).

The effect of flue gas conditioning on the performance of full size electrostatic precipitators has been tested on fly ash resulting from the combustion of coal from the Northern, Western and Southern coal fields at six different power stations. Table 5.1 gives a list of the conditioning systems permanently installed and grouped to show which coal is being burnt at the power stations. Fig. 5.1 sets out the improvement in the value of the EMV for ash from each of the three coal fields. The top of the unshaded vertical column gives an estimate of the normal performance level without conditioning and the shaded area gives the range of improvement obtained with conditioning. All measurements were made for the precipitators operating at their normal SCA's and temperatures.

In general, the electrostatic precipitating properties of fly ash from all three coal fields is improved by both acid and ammonia conditioning. The trend of the data available on full size plants indicates that acid conditioning is more effective than ammonia, although it is not always the preferred system.

There are several anomalies which occur at some of the older plants. At one of the stations burning Northern coal, conditioning with ammonia is very successful, where as excessive concentrations of acid are required to obtain the same result. At another station, also burning Northern coal, acid conditioning is very effective but ammonia has never worked satisfactorily. In the former case, tests on a pilot precipitator with specially designed conditioning unit showed that the fly ash could be conditioned adequately with acid. This and other evidence suggests that the failure to condition with one of the agents is not a function of the fly ash itself but is associated with the injection system or the overall operating conditions of the plant.

The fly ash from the Western coal field has been successfully conditioned with acid and ammonia. In this case, the improvement with ammonia is only temporary with the performance falling off dramatically after only several days in service. Pilot scale tests confirm that this

TABLE 5.1 - PERMANENT CONDITIONING INSTALLATIONS IN ECNSW

Coal Field	Permanent Installations			Remarks
	Agent	No. Power Station	Typical ppm v/v	
Northern	Ammonia	3 (4)	40 - 55	Ammonia system is being installed at a 4th power station.
	CAL	1	50 - 80	
	Acid	1	50 - 60	
Western	Acid	1	65 -75	Ammonia works but performance decays with time. Not as good as acid.
Southern	Ammonia		20 - 30	
	CAL	1	160 - 20	
	Water			

The injection rate of CAL is expressed as NH_3 equivalent and acid as SO_3 equivalent.

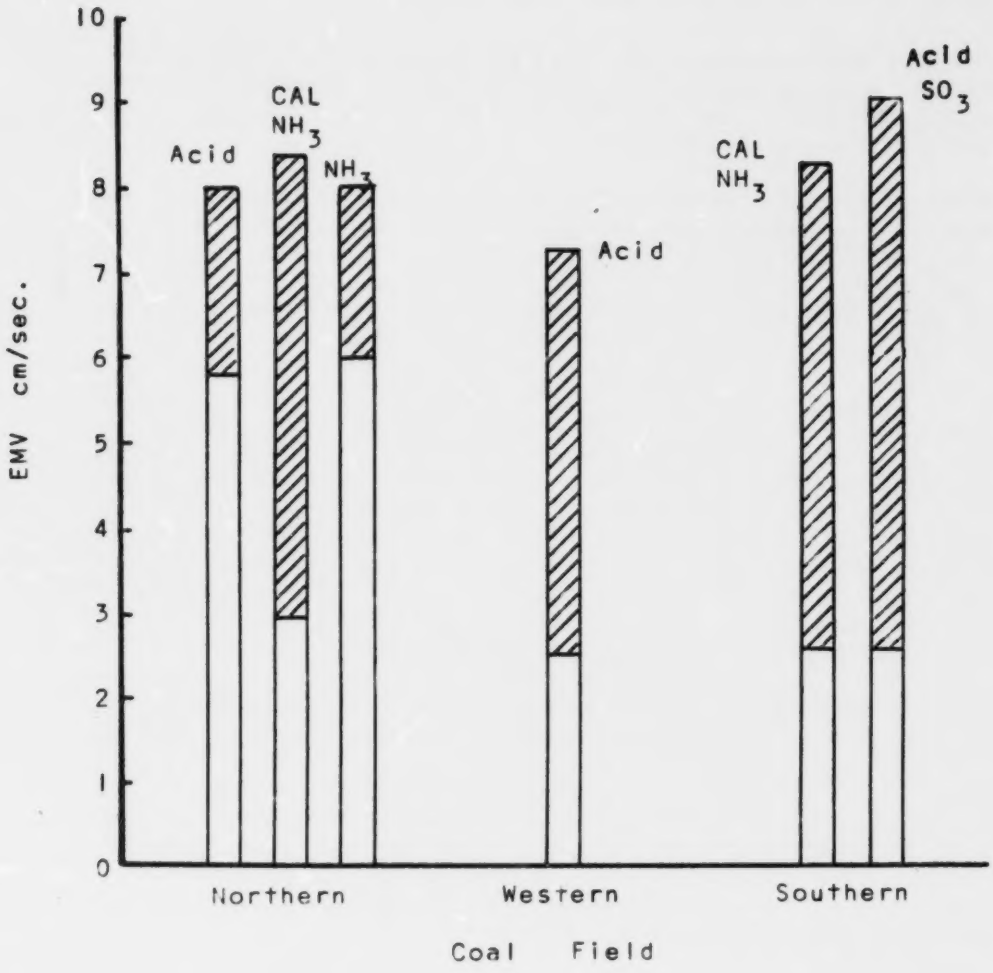

Figure 5.1 Effect of Flue Gas Conditioning on the EMV of Full Size Electrostatic Precipitators.

ash can be conditioned with ammonia but they also indicate that the improvement is not as large as with other ashes.

The Southern coal field ash has been successfully conditioned with ammonia, acid and SO_3. This is of particular importance as this is an acidic ash and it was once thought that it could only be conditioned with a basic agent.

Where it is possible to use either ammonia or acid conditioning, power station staff prefer to use ammonia. The main advantages being that a very simple injection system is required, it is easy to operate, little maintenance is required, operating costs are low and ammonia is safer to handle than acid. In a number of applications where only a moderate improvement is required ammonia conditioning is the natural choice.

One remarkable feature of the conditioning tests is that conditioning has not resulted in very high values for the EMV. In no case does this exceed 8 cm/sec and in the modern precipitators it only improves the day by day performance to the acceptance test level. In the older plants, the lack of improvement is not surprising as the main limitation is probably the unsatisfactory design of the precipitators themselves. It is more difficult to explain the relatively low EMV in the well designed units. It seems likely that once the overall efficiency exceeds 99%, other factors associated with the operation of the full size precipitators may limit the EMV to about this value. This could include such factors as reintrainment, scouring, end leakage and the number of submicron particles in the size distribution of the fly ash.

The presence of the mechanical collectors in the older plants does not appear to affect the conditioning of the fly ash. It is common practice to remove the rotors as it is considered that they do not contribute to the overall performance level of the ash collecting system for reasons already given in Section 3.4.

5.4 Conditioning During Pilot Precipitator Tests (11)(14).

During many of the pilot precipitator tests, efficiency measurements were made during the injection of several conditioning agents. The main systems used are given below.

(i) Stabilized SO_3.

This comprised a drum of stabilized sulphur trioxide, a metering rotameter and a length of heated feed pipe to the point of injection in the inlet pipe of the pilot precipitator. The liquid sulphur trioxide was gravitated from the drum via the heated pipe to the inlet duct where vaporization occured.

(ii) Sulphuric Acid.

The equipment comprises an electrically heated evaporator which vaporises the liquid, and appropriate injection pipes. The

resultant vapor may be injected into the gas stream before the economiser or after the air heater.

(iii) Ammonia

Ammonia gas obtained from a cylinder of anhydrous ammonia is injected into the inlet duct to the pilot precipitator upstream of the heat exchanger.

Fig. 5.2 shows the effect conditioning has on the EMV of ashes from the different coal fields, as measured by the pilot precipitators. Most of these measurements were made in the temperature range 240 - 300°F and SCA's 150 - 360 ft^2/kcfm. The figures in brackets are the concentrations in ppm on a v/v basis.

5.5 Effect of Conditioning on Fly Ash Properties.

The flow properties of the fly ash are affected to some extent by conditioning. In the modern plate precipitators with moderate rates of acid or ammonia conditioning this is not noticeable in the flow and handling properties of the ash and no problems are normally encountered. If excessive acid is used the fly ash becomes sticky and fallout of relatively large acidic agglomerates occur from the stack. Ammonia does appear to increase the adhesion of the ash making it more difficult to remove from the collecting plates of the older plants where the acceleration levels are very low. In this case it is necessary to wash the plates down every two weeks. This is not necessary for the unconditioned ash.

Sulphur trioxide and acid conditioning significantly reduce the resistivity of the fly ash. Measurements made with the Kevatron Electrostatic Precipitator Analyser gives values well below 10^{10} ohm-cms. The mechanism of conditioning with Sulphur trioxide has been extensively investigated.

The mechanism of ammonia conditioning has not been thoroughly investigated. It clearly affects the performance of the precipitator by improving its efficiency and increasing the operating voltage level. The change in the electrical characteristics is consistent with a reduction in ash resistivity. In-situ resistivity measurements have shown a one order of magnitude reduction for Western fly ash, and in the case of the Hunter Valley fly ash, the resistivity was reduced to values well below 10^{10} ohm-cms. Other in-situ measurements have not shown such a large reduction in resistivity due to ammonia conditioning.

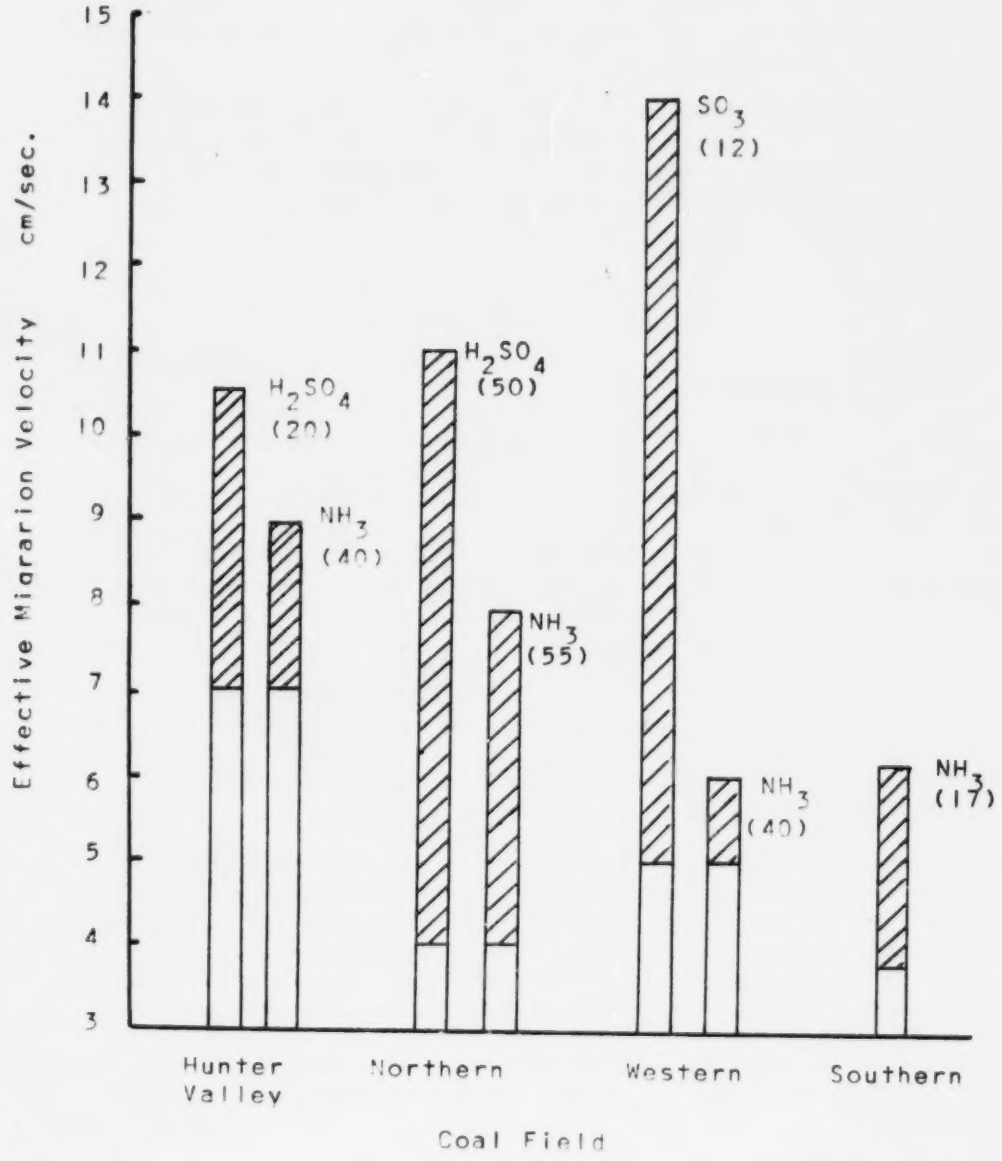

Fig. 5.2

Effect of Flue Gas Conditioning on the EMV of Pilot Precipitators.

CHAPTER 6

THE CSIRO TECHNICAL SCALE COMBUSTION AND ELECTROSTATIC PRECIPITATION FACILITY

6.1 Introduction

Although the in-situ pilot electrostatic precipitator tests, as described in the previous chapter, provide very useful information about the precipitating properties of fly ash, they do have some limitations. These tests are expensive, they require a large number of man-hours and have limited flexibility. In order to overcome some of these limitations, the Mineral Research Laboratories of the Commonwealth Scientific and Industrial Research Organization (CSIRO), undertook to construct a technical scale combustion and electrostatic precipitator rig which could be set up and operated in their own laboratory.

The basic objective of the project is to model in the laboratory both the combustion and precipitating conditions that occur in full size units, so that forewarning of precipitation difficulties can be given for unfamiliar coals and guidance on plant parameters offered.

In the ideal case, such an arrangement could be expected to predict exactly how a full scale electrostatic precipitator will perform under given conditions. In practice however, it is almost impossible to reproduce the full scale conditions. The minimum requirement therefore is that the technical scale unit reproduces the essential features of the full size units so that it can be expected to at least rank the coals as far as the precipitating properties of their fly ash is concerned. A possible extension is to find some empirical relationship between the performance of the technical scale and the full size units.

6.2 Experimental Apparatus (7)(28).

The experimental arrangement is shown in Fig. 6.1. The pulverized fuel furnace is a down fired U-shaped designed for a nominal heat release rate of 15,000 BTU/ft^3 hr., equivalent to a bituminous coal feed rate of about 60 lb/hr., and is built of high temperature refractory brick with an outer layer of insulating brick. The coal burner is located in the centre of the combustion chamber roof and the hot gases and fly ash leave the combustion chamber via a short horizontal duct leading to a vertical flue.

The gas cooling system comprises water cooled copper coils over which the hot flue gas passes. The temperature is controlled by the water flow rate into each of the cooling coils. Only part of the gas produced in the furnace is passed through the precipitator. The remainder is by-passed to the stack through a cyclone collector to remove the ash.

The electrostatic precipitator is one tube of a standard industrial tube type electrostatic precipitator. It comprises a tubular collecting electrode 10 inches in diameter and 10 ft. long surrounding a discharge electrode wire axially suspended and kept taut and vertical by means of a weight attached to its lower end. Tumbling hammers are used for rapping both the collecting and discharge electrodes. The gas enters the chamber at the bottom and flows out of the top. The gas temperature is kept constant at the desired value by thermostatically controlled electric heaters.

The precipitator is energized from a transformer rectifier set with a maximum rating of 60 kV and 60ma. The rectifier is connected full wave, and full voltage is derived from a voltage doubling circuit. Manual voltage control is provided by means of a variac type transformer.

The main parameters of the electrostatic precipitator are summarized in Table 6.1

TABLE 6.1 - MAIN PARAMETER DIMENSIONS OF CSIRO TECHNICAL SCALE ELECTROSTATIC PRECIPITATOR

Collecting plate.	Length	ft.	10.0
	Diameter	ins.	10.0
	Area	ft^2	26.2
Discharge electrode diam.		ins.	0.1
Cross section area		ft^2	0.547
Flow rate		cfm	102.
SCA		ft^2/1000 cfm	260.
Gas velocity		ft/sec	3.1
Rectifier Rating.	Voltage	kV	60.
	Current	ma	60.
Typical corona current		ma	1.1
Corona current density		μa/ft^2	42.

The performance of the electrostatic precipitator is measured by sampling the flue gas at the input and output and calculating the efficiency on the basis of the weights caught in the sampling thimbles.

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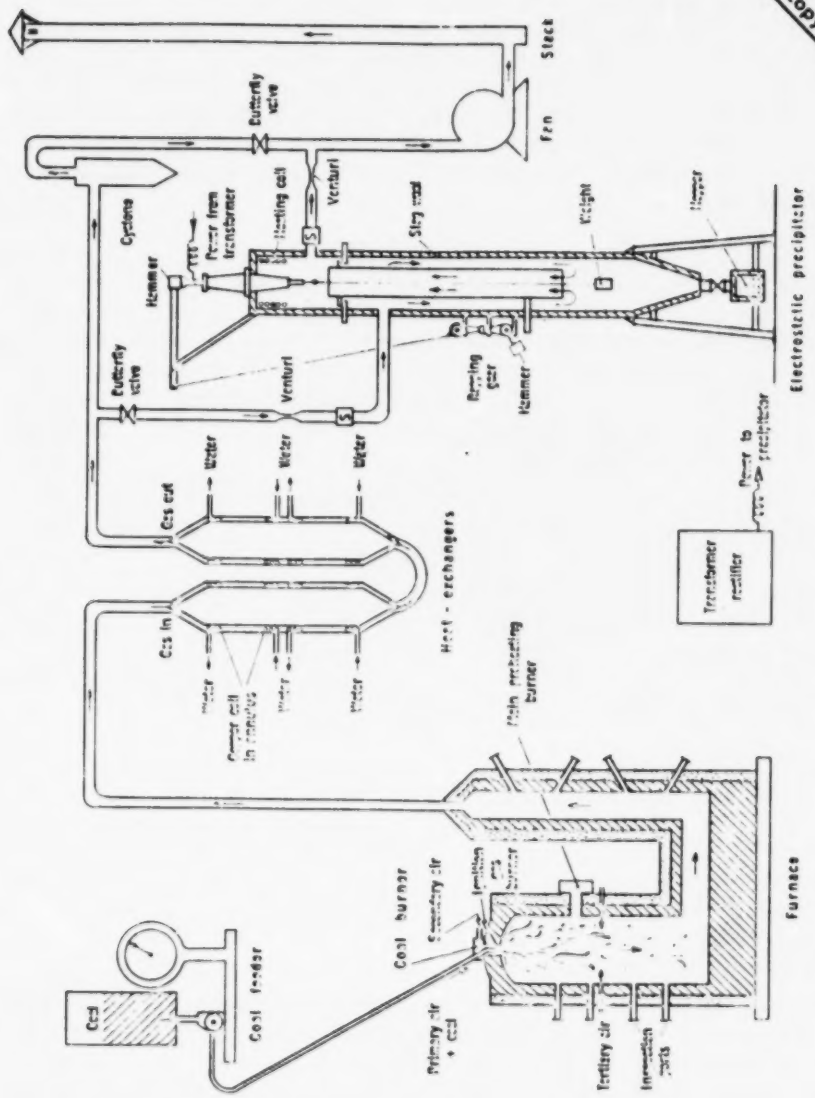

Fig. 6.1

CSIRO Pulverized fuel rig and Electrostatic Precipitator Facility.

6.3 Test Procedure

Before a test series the furnace is preheated with town gas for 16 hours, after which it is operated at a coal feed rate of 60-70 lbs/hr., the actual rate being adjustable to give a furnace heat rate similar to that of the proposed boiler. The combustion air is controlled to give an excess air rate similar to the likely operating value for the full size power plant. The combustion air temperature, flow rate, furnace wall temperatures, gas temperature and the coal feed rate are all monitored. The temperature of the flue gas to the precipitator is adjusted to the required value by the cooler. Any deposit in the cooler is cleaned out at the end of each day.

After the coal has been introduced into the furnace, conditions are allowed to stabilize. At this stage the corona voltage current characteristics are measured and then the current is set at 1.1 ma, or some other predetermined value and the tests commenced. It is usual for three one hour tests to be carried out each day. At the end of each day the corona voltage current characteristic is again measured and the remaining ash removed by rapping and hosing down. Ash samples are taken from the collecting electrode after each test.

6.4 Limitations

While the test rig has a number of significant experimental advantages over the pilot precipitator, it is acknowledged by the CSIRO that it has some limitations in simulating full scale combustion and precipitation. Some of the possible limitations are discussed below but as will be seen, many of them are not important.

(a) In the experimental furnace it is possible to simulate the size distribution of the pulverized coal, the rate of heat release for unit furnace volume and the amount of excess air used during combustion. Since the furnace is refractory lined, it might be expected not to accurately simulate a modern power station boiler furnace which is lined with relatively cool water tubes. CSIRO know of no essential difference in the chemical composition of the resulting fly ash from that obtained from the full size furnace.

(b) Because of the aerodynamics of the experimental furnace, up to about 50 percent of the ash is retained in the furnace where as in modern power station furnaces only 15 to 20 percent is retained. It is also likely that the larger quartz grains and heavier ion-bearing components tend to be left behind in the technical scale furnace. Because of this and the drop out in the ductwork, the particle size entering the electrostatic precipitator is finer than is usually encountered in industrial units. The grain loading is also lower, although it is not unreasonably so. In one series of tests, inlet dust loadings of 2 to 6 grains/ft^3 at NTP was normal.

(c) The test precipitator is a tubular type with a small total collecting area in which the gas flow is vertical along the length of

the discharge wires. The usual full size precipitators are plate type in which the gas flows horizontally and at right angles to the discharge wires.

Although the geometrical arrangement of the electrodes differ from the full size unit it seeks to model, the diameter of the discharge wire and its distance from the collecting electrode are similar. Hence it is not unreasonable to expect the charging and precipitating electric fields of this precipitator to correspond closely to those of a full size plate precipitator.

(d) The technical scale precipitator is not sectionalized and this results in a lower average EMV than if it were sectionalized.

(e) The collecting area of the technical scale precipitator is only 26.2 ft^2. Because of this it is generally considered that a precipitator with such a low plate area will operate at much higher voltages than a unit with a much larger collecting plate area. This may be true for precipitators collecting low resistivity dusts but it need not be applicable for precipitators collecting high resistivity fly ashes since the voltage level is determined by the onset of back corona and is not dependent on the normal sparking characteristics. The CSIRO have conducted many of their tests at a current density of 48 $\mu a/ft^2$. At this current density the precipitator would normally operate in the back corona region for high resistivity ashes and hence at its maximum voltage.

One of the complications experienced by the CSIRO with their testing is that the voltage current characteristic sometimes changes throughout the day as the deposited layer on the collecting plate builds up. Initially the voltage is high but often it reduces during the test period.

This voltage change, together with the good alignment of the electrodes, probably results in better electrical voltage levels than in a full scale precipitator and will cause the precipitator to give more optimistic results. This is counter balanced to some extent by (b) and (d) above.

6.5 Results and Discussion (10)(15)(28)

The CSIRO has carried out a very extensive range of tests on a large number of coal samples from New South Wales, Queensland and one of the low sulphur coals from the United States. Many of these test results are not available for inclusion in this report.

One of the most extensive series of tests which may be reported, was carried out for the ECNSW. These tests were part of a testing program aimed at investigating the electrostatic precipitation properties of fly ash from the Hunter Valley coal field. All together a total of 17 different coal samples were tested with a sulphur content varying from 0.33 to 0.99 percent and an ash content from 10.2 to 32.8 percent. A detailed report covering these tests was prepared by the CSIRO and also reported in the general literature.

It is of considerable importance to know the extent to which this technical scale testing rig simulates the performance of the full size units. The CSIRO acknowledges that because of the difficulties in modelling, it cannot exactly represent a full size unit. However, they conclude, "it would appear that despite obvious differences between the experimental rig and full scale power station plant, and notwithstanding the ash deposition problem in the technical scale furnace, there is no serious difficulty in predicting from the test rig results the relative performance of full scale plate type precipitators on fly ashes from different coals."(10)

The electrostatic precipitating properties of the different fly ashes as measured by this rig have been compared with measurements made by the in-situ pilot precipitator and in some cases with full size precipitators. The comparison of the characteristics of three different NSW fly ashes may be seen in Table 6.2. A temperature of 250^{o}F and an SCA of 260 ft^{2}/kcfm. is taken as the basis for the comparison. The coals are arranged in their order of difficulty of collection and this agrees with that predicted by the CSIRO technical scale rig.

It has been traditional to expect the efficiency of collection of fly ash to be related to the sulphur content of the coal. Measurements by the CSIRO technical scale rig on coal from NSW, Queensland and one sample from the United States have not been able to show that any correlation exists. Coals with sulphur contents as low as .35 percent have given remarkably good performances(28). This is in agreement with results obtained from the full size and pilot electrostatic precipitators.

TABLE 6.2 - COMPARISON OF EMV

Temp = 250^{o}F SCA = 260 ft^{2}/kcfm

Coal Field	Effective Migration Velocity cm/sec		
	CSIRO	Pilot Precipitator	Full Size Precipitator
Northern	8.5	8.5	7.0 - 8.5
Hunter Valley	7.9	7.5	N.A.
Southern	5.4	3.0 - 4.2	2.5 - 3.5

N.A. - not available

CHAPTER 7

LABORATORY TECHNIQUES FOR EXAMINING ELECTROSTATIC PRECIPITATING PROPERTIES OF FLY ASH

7.1 Objective

One of the objectives of a number of research efforts overseas has been to devise tests by which the performance of coals and the properties of the resultant fly ash can be predicted from small bore core samples. In Australia, an attempt is made to do this by the combined efforts of the Australian Coal Industry Research Laboratories Ltd. (ACIRL), Ryde, N.S.W., Wollongong University College (WUC), and the Electricity Commission of New South Wales. The burning of the coal sample together with physical and microscopic examination of the resultant fly ash is carried out by ACIRL and the electrical properties of the ash is measured by WUC.

The ECNSW and Bechtel of the United States on behalf of various clients, have both made use of this facility.

7.2 ACIRL Small Furnace (12)

The apparatus consists of a conventional laboratory tube furnace as shown diagramatically in Fig. 7.1. The central mullite tube 3.8 cm bore and 100 cm long, is heated by a number of 'Crusilite' hairpin and spiral elements to give a maximum temperature of 1,500^{o}C. Pulverised coal is fed into the path of incoming gases of desired composition at the top of the tube and fly ash is collected from the bottom of the tube.

The coal feeder consists of a stirred glass hopper leading to a screw feeder driven by a variable speed motor. Coal is then gravity fed into the furnace.

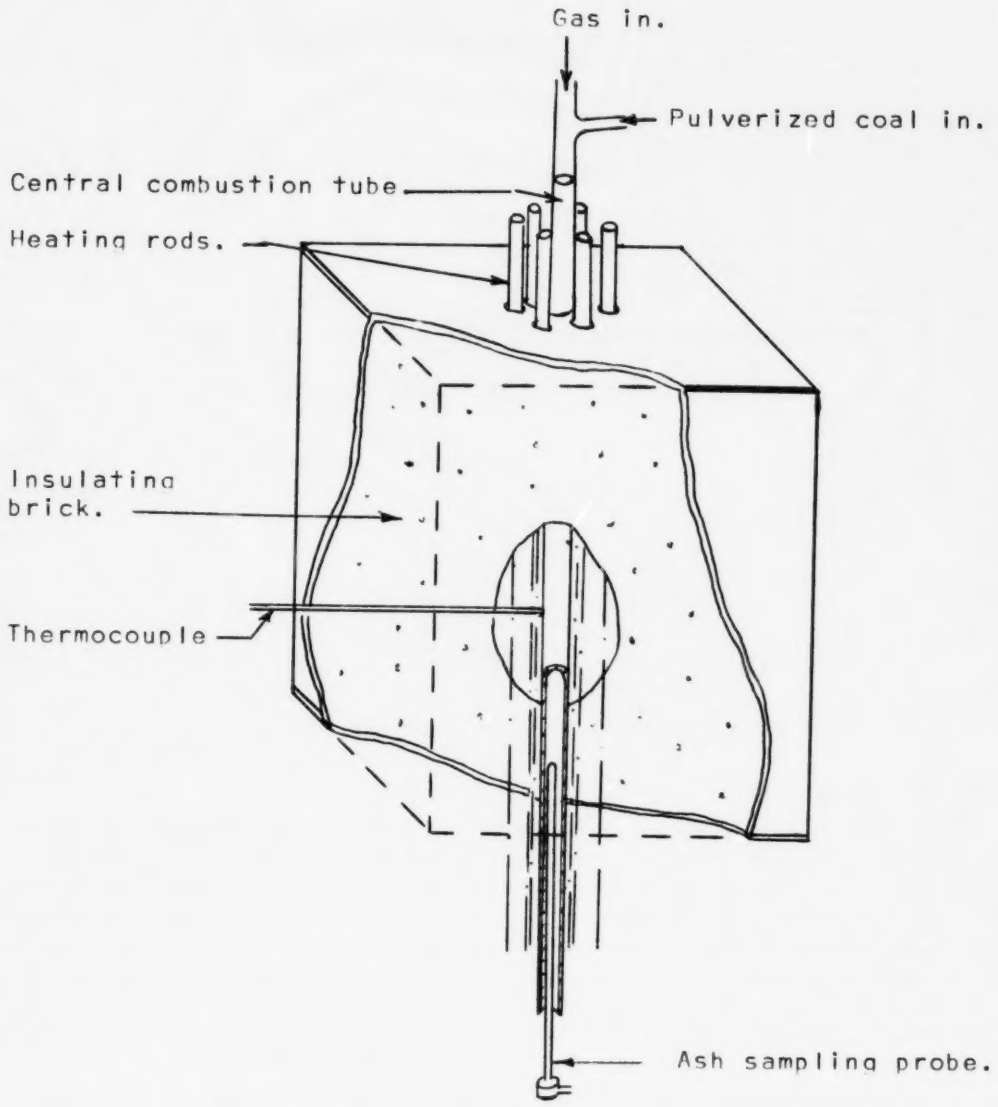

Fig. 7.1

ACIRL Small Laboratory Furnace

Incoming gases are metered through a system of manometers and passed through a mixing bottle prior to entry at the top of the furnace. In this fashion both total flow and gas composition is closely regulated.

The furnace is operated at approximately maximum temperature with oxygen concentrations adjusted to provide the desired gas compositon for specific operations. A set of furnace conditions would be:-

Furnace temperature at centre	- 1,500°C
Gas compositon	- 88% O_2, 12% N_2
Gas Flow (S.T.P.)	- 1800 cc/minute
Coal feed	- 0.2 grams/minute
Residence time	- 2.4 seconds

At 1,500°C the furnace power is 5kW. With a feed rate of 0.2 grams/minute of 12,000 B.T.U.lb coal, the energy from combustion is 0.1kW or 2% of the total input.

The original and still main performance of this furnace is to predict from a number of small samples, usually borecores, the likely performance of unused and unknown coals in large scale industrial firing. The use of this furnace to produce the fly ash which may be tested physically, microscopically and for its electrostatic precipitating properties, is one of the specialised applications for which it may be used.

7.3 The WUC Test Rig and Analyser (17)(27)

The arrangement of the environmental test chamber is shown in Fig. 7.2. A synthetic gas mixture is made up of appropriate amounts of SO_2, O_2, CO_2 and N_2, and passed through a humidifier to the reaction vessel. This contains the resistivity measuring cell in which the sample of fly ash is placed and the resistivity measured between two parallel plates. Typical resistivity temperature curves for varying humidities are obtained with excellent repeatability.

The output from the environmental chamber may be fed into the Kevatron Electrostatic Precipitation Analyser 223, details of which are shown in Fig. 7.3. The fly ash sample is introduced into the gas stream after the humidifier and then electrostatically collected in the upper chamber of the Analyser. Although the efficiency of collection may be measured, at the present stage of development it is being used to examine the corona voltage-current characteristics in order to determine the voltage at onset of back corona and spark-over. It is considered that this measurement gives an indication of the electrostatic precipitating properties of the fly ash. Fig. 7.4 shows an example of the type of results obtained for an ash which has been conditioned with ammonia.

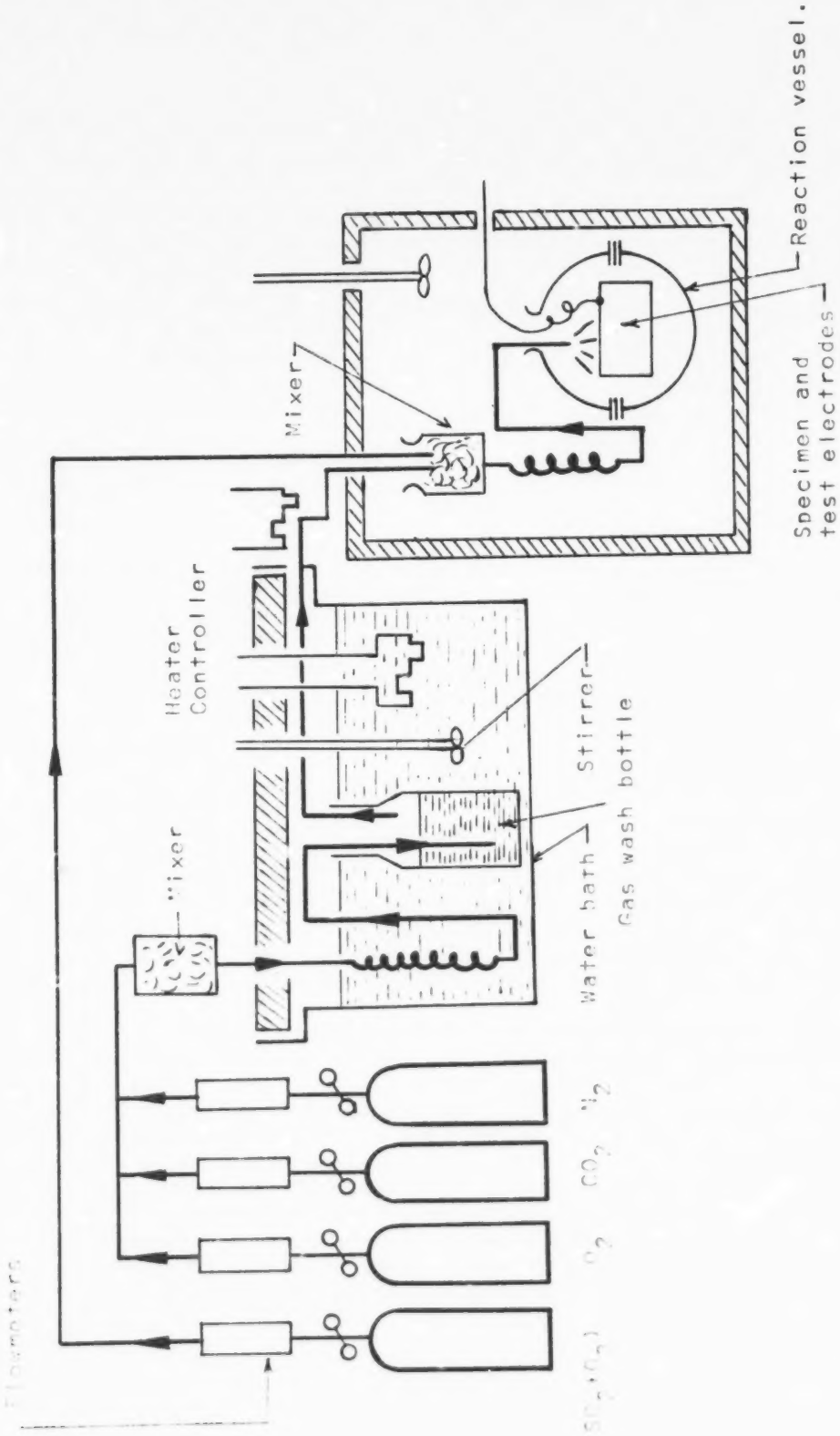

Fig. 7.2

WUC Test Rig for Measuring Resistivity under Varying Environmental Conditions.

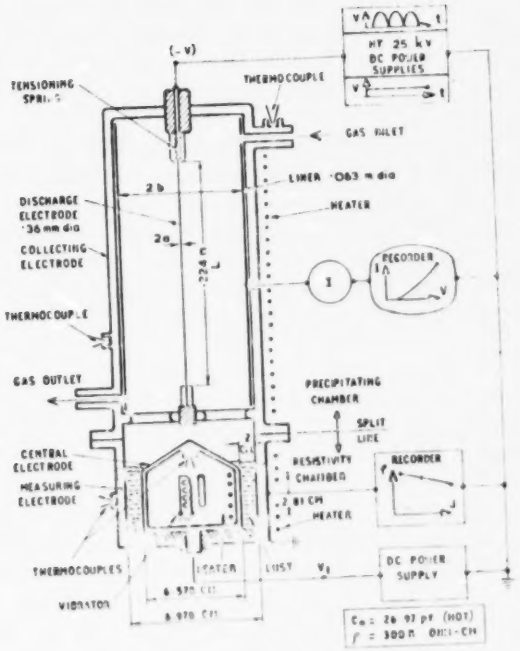

Fig. 7.3

Kevatron Electrostatic Precipitator Analyser 223.

Gas to be examined enters the inlet to the precipitator chamber where the particles are removed and corona characteristics measured. After rapping the deposit falls into the lower chamber, where after compaction, resistivity is measured.
(2a) = 0.35mm; (2b) = 6.3cm; L = 0.324 m.

7.4 Discussion

In order to check the effectiveness of the modelling of the ACIRL furnace as far as the electrical properties of the fly ash is concerned, a sample of coal was taken from the hoppers of one of the power stations and burnt in the ACIRL furnace. At the same time a sample of the fly ash produced by the pwer station boilers was removed from the electrostatic precipitator hoppers. The resistivity of both these ashes was then measured in the environmental chamber for similar conditions and agreement to within a factor of 2 to 3 was obtained. Similar results were obtained with other test samples. Because of variations in the coal over a 24 hour period, this scatter of results is quite normal.

It is still an open question as to whether the resistivity measured in this manner is the same as the in-situ value. Fig. 7.5 shows some in-situ measurements made on the fly ash at Tallawarra. These measurements were made at different times so direct comparison is not possible. Even allowing for this, the known variations that occur in the coal and the well known difficulty in measuring in-situ resistivity, the values are in good agreement with only a decade difference between them.

It may well be argued that the in-situ resistivity would not be too different from that measured in this laboratory apparatus. The one important flue gas component which significantly affects resistivity is SO_3. The percentage of this gas in the case of high sulphur coals materially affects the resistivity but it seems likely that for coals with less than 1% sulphur, the SO_3 content is no longer important and that the resistivity is determined by other factors as well. This view seems to be supported by evidence in Australia that the sulphur content of the coal does not give any correlation with the electrostatic precipitating properties of the ash as measured by either the full size precipitators, the CSIRO technical scale or the pilot precipitators.

It is not considered at this stage that sufficient data has been obtained to relate any of these readings directly to the EMV used in sizing a full size precipitator. However, it is considered that both the resistivity and corona measurements may be used to rank the coals as far as the electrostatic precipitating properties of their ash is concerned.

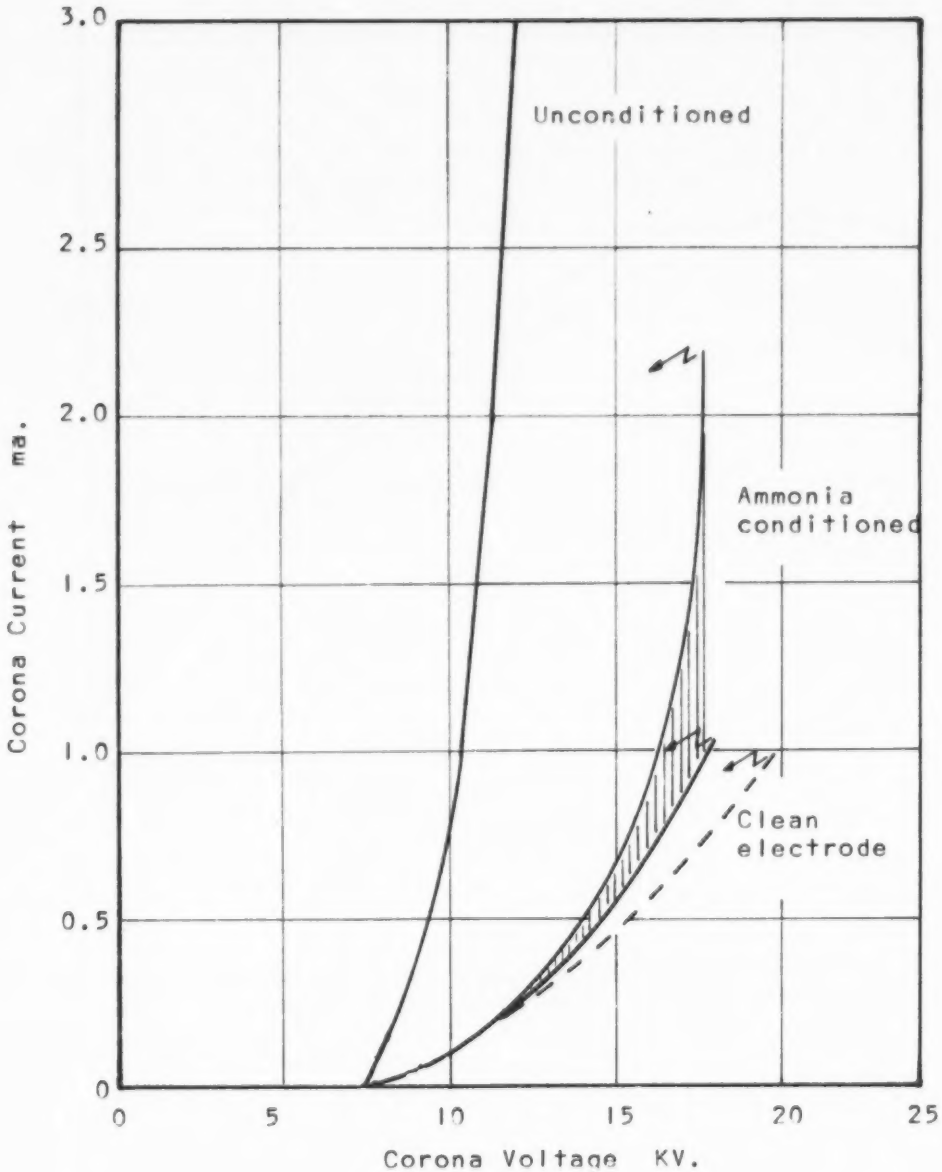

Fig. 7.4

Corona Characteristics of the Kevatron 223 with and without Ammonia Conditioning. Temperature = 143°C.

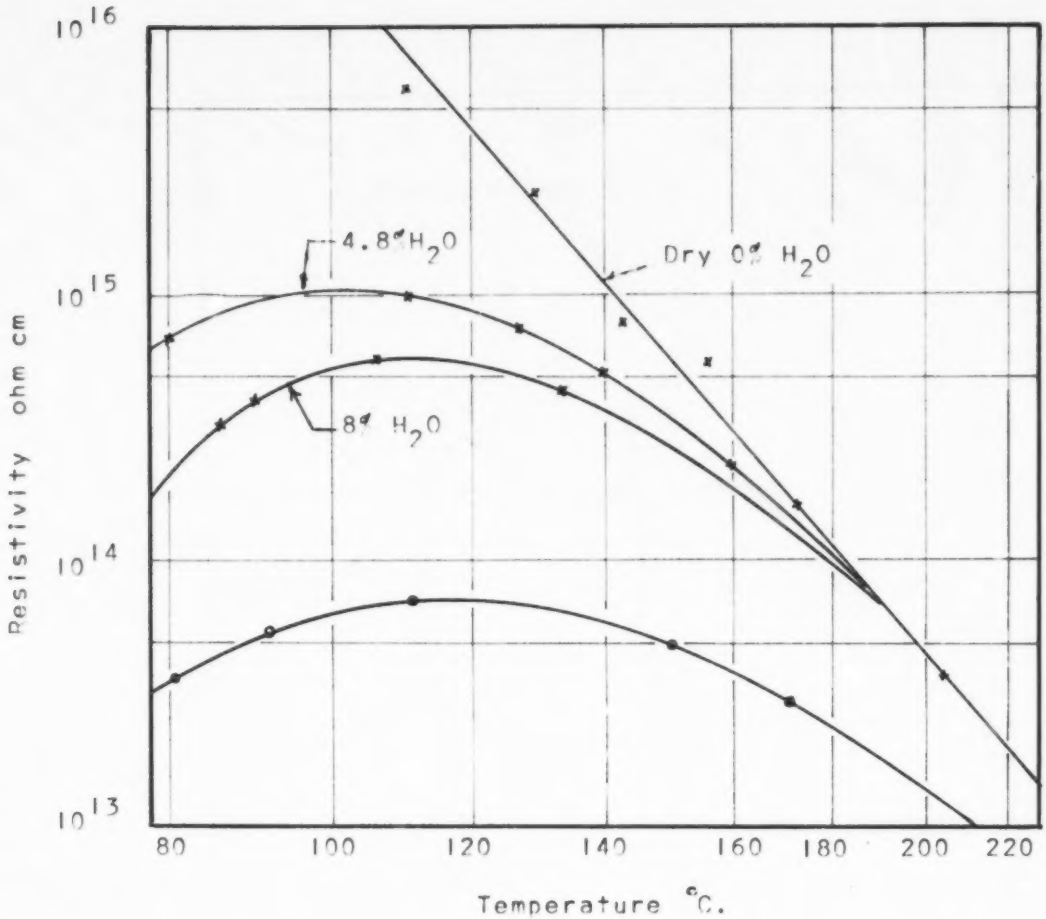

Fig. 7.5

In-situ Resistivity Compared with Resistivity Measured in the Laboratory with Synthetic Flue Gas.

c In-situ 1970.

x Laboratory 1971. (Synthetic flue gas)

CHAPTER 8

SUMMARY OF SALIENT FEATURES

In this chapter an attempt is made to summarize the main features which characterize the electrostatic precipitation of fly ash from low sulphur coals. Some of these features highlight how the collection of this fly ash differs from the collection of ash from the high sulphur coals.

1. The fly ash has very high in-situ resistivity with maximum values above 10^{14} ohm-cm occuring in the temperature range 240 to 300°F. At temperatures above 800°F, the resistivity drops to below 10^{10} ohm-cm.

2. These fly ashes are very difficult to collect with electrostatic precipitators, in some cases requiring units with SCA's in the order of 600 ft^2/kcfm if no gas conditioning is used. In order to assist in the collection, the flue gas temperature in the collectors is in the order of 260°F, and it is proposed in the future to operate one unit at 220°F. The EMV's are very low with values varying from below 3 cm/sec up to a maximum of 8 cm/sec.

3. Good rapping is necessary if high performance is to be obtained. Transverse accelerations of 60 g are necessary in order to adequately remove the deposited layer from the collecting plate.

4. In many instances the electrostatic precipitators operate with some back corona current flowing. Voltage levels are down and current densities are usually lower than is required for collecting ash from high sulphur coals. The useful corona current density may be in the order of 8 $\mu a/ft^2$ and the back corona current may be 2 to 3 times this value. Optimum operating conditions are often found to be at a voltage level just below sparking.

5. It is a characteristic of electrostatic precipitators collecting high resistivity fly ash that maximum performance can only be obtained by very careful tuning and maintaining the units in excellent mechanical and electrical condition.

6. The performance of all the Australian ashes can be improved by flue gas conditioning. Sulphur trioxide probably gives a better performance level although good results have been obtained with ammonia. Because of its simplicity and economy, ammonia is the preferred conditioning agent. In no case however does the EMV of a full size precipitator with conditioning exceed 8 cm/sec. The sulphur trioxide is obtained from sulphuric acid and the ammonia from anhydrous ammonia and more recently from Concentrated Ammonical Liquor. (CAL)

7. The sulphur content of the coal cannot be used as a guide to determine the electrostatic precipitating properties of a fly ash. This is probably true for coals with a sulphur content of less than 1 percent, although it need not be so for coals with higher levels.

8. In Australia, good indication of the precipitating properties of unknown fly ashes has been obtained from pilot precipitator tests, the CSIRO test rig and the ACIRL-WUC test facility.

9. Pilot Precipitators have been used very successfully to predict the electrostatic precipitating properties of fly ash with unknown characteristics. Reasonably consistent results have been obtained, and after the application of an appropriate scaling factor, these are in agreement with results obtained from full size electrostatic precipitators.

10. The CSIRO test facility provides a valuable method of quickly and economically ranking the precipitating properties of an unknown fly ash.

11. By using bore core samples the ACIRL-WUC laboratory scale test facility provides a very simple and economic method of measuring some important parameters of fly ash samples which may then be used to assist in the sizing of electrostatic precipitators.

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Although the data and information recorded in this report has been gathered from many different organizations and as a result of discussions with many people, its accuracy and the conclusions arrived at are the sole responsibility of the author.

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